A Brief History of Time

INTRODUCTION

BRIEF BIOGRAPHY OF STEPHEN HAWKING

Stephen Hawking was born to science researchers Frank and Isobel on the 300th anniversary of the death of Galileo Galilei, Jan 8, 1942. He grew up in St. Albans in England as the eldest of four children. He graduated from Oxford University with top grades in physics, before moving to Cambridge University to study cosmology. In 1963 he was diagnosed with motor neurone disease, also known as Lou Gehrig's disease, and was given two years to live. Nevertheless, he married his wife Jane Wilde in 1965, with whom he had three children, and completed his PhD. He went on to become a member of the Royal Society in 1974 and Lucasian Professor of Mathematics at Cambridge in 1979, just as Sir Isaac Newton had centuries before. He spent much of his career studying both the vastest and minutest details of how the universe works, seeking a way to unify Albert Einstein's theory of general relativity with quantum mechanics. In 1985 an emergency procedure took away his ability to talk, but a cutting-edge device developed at Cambridge University allowed him to control a computer voice by moving his cheek muscles. His work on black holes earned him fame among scientific circles, but his public prominence came with the publication of *A Brief History of Time* in 1988. After the book became a bestseller, he was considered a celebrity scientist. Hawking divorced Jane in 1995 and married his nurse Elaine Mason. The two split in 2006. In 2014, a Hollywood film, *The Theory of Everything*, celebrated his life and struggles with his disability. Hawking continued to push the boundaries of humanity's understanding of the universe, publishing many works both in academic circles and for public audiences. Hawking passed away on March 14, 2018 at age 76.

HISTORICAL CONTEXT

A Brief History of Time discusses the development and history of cosmology from Ancient Greece all the way through to the 1980s, and as such covers a broad range of historical periods. Over that time, discussion of the wider universe moved from a philosophical or religious matter to one of science and, later, primarily physics. Hawking notes that while an educated person in Sir Isaac Newton's time could have a basic understanding of all human knowledge, today scientists specialize so minutely it is hard for them to keep fully up to date with new findings even within their own subject. Thus, the history of science is one of ever-increasing complexity.

RELATED LITERARY WORKS

While Hawking updated and extended *A Brief History of Time* in later editions, he also released works in later years to discuss more up-to-date theories and trends in physics. For example, *The Grand Design*, written with Leonard Mlodinow and published in 2010, focuses on the idea that there is no universal rule that applies to all physics, in direct contrast to the major argument of Hawking's earlier book. Instead, the authors explain M-theory, which posits there could be innumerable alternate universes, and while the rules that apply to our own support the existence of life, that is most likely not so for the majority of other universes.

KEY FACTS

- **Full Title:** A Brief History of Time: From the Big Bang to Black Holes
- **When Written:** 1983
- **Where Written:** Cambridge, UK
- **When Published:** April 1, 1988
- **Genre:** Science, Non-Fiction
- **Point of View:** First-person

EXTRA CREDIT

No formulas. Hawking's editors told him that for every mathematical formula he included in the book, the readership would halve. They only permitted him to include Einstein's famous equation, E=mc2 "where E is energy, m is mass, and c is the speed of light."

Family man. As his battle with motor neurone disease intensified, Hawking wanted to support his family with the proceeds of a book written for mass readership. He wrote *A Brief History of Time* partly to bring cosmology to a wider readership, and partly to support his family with the profits.

PLOT SUMMARY

Where did the universe and everything in it come from, and where is it all headed? New technology has allowed modern science to offer answers to such questions. First, Stephen Hawking details some of the major scientific breakthroughs throughout history that have brought our understanding to this point.

Though in Ancient Greece people worked out that the earth is round, thinkers such as Aristotle still thought the earth was at the center of everything else. This theory wasn't really challenged until 1514, when Nicholas Copernicus showed that the planets, including the earth, orbit the sun. In 1687, Sir Isaac

Newton devised his own laws related to gravity, theorized that all stars should exert this force on one another, and wondered whether the universe was infinite. In 1929, Edwin Hubble discovered that galaxies everywhere are rapidly moving away from each other. The idea that the universe is expanding, in turn, suggested there was a time when everything was in a single, tiny, infinitely dense place. God, Hawking notes, could fit into this theory.

Science's ultimate goal is to find one theory that ties all the others together. For now, the two main partial theories scientists have include the general theory of relativity and quantum mechanics. The former focuses on gravity and massive celestial bodies, while the latter deals with the tiniest types of matter known to humanity. These theories are inconsistent with each other, however. Scientists are still search for a unifying theory to fulfill to the deepest longing of humankind: to understand where we come from.

Newton put forth the idea that objects are naturally in motion, and that forces cause them to speed up or slow down. This challenges the idea of absolute space; think of a ping pong ball bouncing on a train going 40 miles an hour. The distance the ball has moved according to someone on the moving train will be very different when compared to the observation of someone outside the train.

The idea of absolute time, however, took longer to overcome. In 1865, James Clerk Maxwell discovered that light has different wavelengths, such as radio waves or microwaves. Albert Einstein later pointed out that light always moves at the same speed and is faster than anything else in his theory of relativity. The general theory of relativity also put forth that gravity warps—bends and curves—space-time. For example, time moves more slowly near objects with larger masses. Thus, though space and time affect objects' movements, objects' movements *also* affect space and time; neither is absolute. Einstein also proposed a sort of antigravity force, or cosmological constant, that would repel objects and explain the (incorrectly) assumed static nature of the universe.

In the mid 18th century, astronomers identified the Milky Way and described it as a spiral galaxy. In the 20th century, Hubble showed that there are galaxies other than our own—and from the red shift seen in these far-off stars, it is clear that these galaxies are moving away from us. This explains why the universe is not collapsing in on itself, without the need for Einstein's cosmological constant—which Einstein deemed the worst mistake of his career.

Russian physicist Alexander Friedmann suggested that the universe looks roughly the same in all directions. This was later proven by measuring the universe's uniform microwave radiation. Friedmann also offered various models of the universe, both finite and infinite, with most featuring a big bang at the beginning. Wider acceptance of the big bang theory came with Roger Penrose's work on black holes, which occur when matter collapses in on itself until it takes up zero size and is infinitely dense. Hawking, then a doctoral student, saw the relevance of the reverse version of this for the big bang theory, and later released a paper to that effect with Penrose.

The Marquis de Laplace suggested in the early 1800s that because modern science seemed to be doing such a good job predicting things, human beings would be able to predict everything if only they knew the exact state of the universe at one point in time. But the end of that idea came when Werner Heisenberg tried to exactly measure the position and velocity of a particle. The more accurately Heisenberg wanted to measure this, the more the light he had to use—which, in turn, would affect the particle's position or velocity. Thus, it was impossible to say exactly where particles were, something scientists now call the uncertainty principle. This lead to the creation of quantum mechanics.

Theories about the atom built up slowly, but by the early 1900s scientists had identified electrons, neutrons, and protons. Murray Gell-Mann won the **Nobel Prize** in 1969 for discovering that these, in turn, were made up of quarks, of which there are different varieties. Every kind of particle also has certain types of spin, which relates to how many times a particle must be "turned" 360 degrees to look and behave the "same." Spin can be used to determine various forces. Matter particles also obey the Pauli exclusion principle, which states that particles cannot exist in the exact same place: they inevitably repulse each other. Further work discovered anti-particles (against which particles collide, resulting in both being annihilated), as well as force-carrying particles that are undetectable apart from their effects on other particles. Force-carrying particles are categorized as either gravitational, electromagnetic, weak nuclear, or strong nuclear forces.

The term black hole was coined in 1969 by John Wheeler, but the idea has been around for 200 years or so. John Michell said in 1783 that any star that was big and dense enough would have such strong gravity that even light could not escape it. While we might not be able to actually see these objects, we could measure the effect of their gravity on surrounding material. This would happen at the end of a star's life, when its energy has been used up—meaning it can no longer fight against its own gravity and begins to collapse. Subrahmanyan Chandrasekhar measured how big a star would have to be to end up as a black hole, which in part earned him a Nobel Prize. Not all stars end up this way, however, especially if they are of a similar size to our own sun.

If black holes can stop light from escaping, nothing else can escape either. The boundary from which nothing can escape a black hole is called its event horizon. Hawking and Penrose showed that at the center of black holes are singularities, points of infinite density and gravity where the laws of physics cease to operate.

Hawking was the first to note that black holes can only grow bigger as more matter falls in. This is similar to the law of thermodynamics, which states that the entropy—essentially disorder or chaos—of an isolated system can only increase. Jacob Bekenstein suggested that the area of the event horizon is a measure of the black hole's entropy. This meant that black holes must emit heat and particles, which has been proven to be true. An old, big black hole could therefore be harnessed to provide massive power output, but we do not have the technology to do so.

Hawking attended a conference at the Vatican in 1981, which reawakened his interest in the start and end of the universe. The Pope told the scientists present not to look at this aspect of science, as it was God's work, but Hawking had in fact recently discussed the possibility there was no beginning to the universe at all, because the universe has no boundary. There are many different theories as to what the early universe looked like, however. In the hot big bang model, the early universe had infinite heat, meaning the particles were moving very, very fast. As the universe expanded, it cooled. Eventually, once the universe cooled off enough, matter clumped together; galaxies formed, then stars, then planets, and finally organisms.

Scientists need a quantum theory of gravity to really know what happened at the beginning, but this doesn't exist yet. The anthropic principle, meanwhile, searches for an answer to the question of why the universe is compatible with the existence of intelligent life; the "weak" version of this principle essentially says that if the universe were not fit for intelligent life, intelligent life would not exist.

The second law of thermodynamics, entropy, states that things tend to get more disordered, so this is one arrow of time. The second arrow of time is psychological and refers roughly to the formation of memories. The third arrow refers to the cosmological arrow of time, in which the universe is expanding. The theory of the universe as having no boundaries and the weak anthropic principle make a case for why these three arrows of time all point forward, and why this is the only situation in which intelligent beings could exist. Even making memories increases disorder, as it takes energy to make a new memory, thus creating more disorder as that energy is emitted.

The question, then, is what happens when the universe eventually starts to contract? Time will not flow backwards, because disorder can still only increase—meaning the thermodynamic and psychological arrows of time would still point forward. The universe would only be suitable for life in the expanding phase, as all celestial bodies would have burned out before the collapsing phase begins.

In some models of the early universe, space-time might have been so disordered that time travel was possible, but observations of the uniform radiation across the universe suggest this was not the case. As time is not absolute, however, it would be possible for space travelers to return to earth in what seems like a short time to them, though thousands of years would have passed in earth's perception of time. Traveling faster than light, however, would allow one to leave point A at the same time as an event and arrive at point B before that event had started. It might also be possible to warp space time to create a wormhole between two points. These "Einstein-Rosen bridges" could allow travel into the past if an advanced civilization could stabilize them.

The quest to unify physics—to bring together the general theory of relativity with quantum mechanics—is ongoing, as scientists only have partial theories so far. Any theory must include the uncertainty principle, and as such the first step must be to incorporate this into the theory of relativity. String theories offer possible answers. They visualize particles as waves on one-dimensional lines in two dimensions of space-time, instead of as dots. Particles are then visualized as waves passing down that "string." The main problem with string theory is that it requires many more dimensions to work—either 10 or 26.

We can still be fairly certain that there is a unifying theory of physics, as the partial theories we have are getting closer and closer to explaining everything. But even if scientists were to find such a theory, they still could not predict everything exactly because of the uncertainty principle. The real aim, Hawking says, is to understand our own existence and, indeed, why anything exists. Once we know that, we will know the mind of God.

CHARACTERS

MAJOR CHARACTERS

Stephen Hawking – The author and narrator of the book, Hawking often appears as an active character given his vital role in the progress of modern physics. He took on a PhD despite his diagnosis of Lou Gehrig's disease, choosing in 1965 to apply Roger Penrose's ideas on black hole singularities to create theories about the big bang. From there, he tackled questions about the large-scale structure of the universe, as well as the workings of the tiniest particles science has yet discovered. Overall, his aim was to help humanity to one day find a unified theory of everything and help the lay person to understand it, so that we might understand the mind of God. Hawking admires humanity's quest for knowledge and makes examples of those who have stood in the way, including himself.

Sir Isaac Newton – Newton published *Philosophiae Naturalis Principia Mathematica* 1689, in which he outlined his theories about the celestial bodies, how they move in space and time, and the math to back it all up. He came up with the idea of gravity, a force that is stronger the bigger and closer an object is. He said the image of a falling apple prompted the idea and showed that gravity caused the planets' elongated orbits. Given this new idea of gravity, which all objects produced, Newton wondered why all the stars didn't fall in on each other; he did not realize that the universe must be expanding. Working from Galileo's measurements, Newton produced his laws of motion and gravity. He was troubled by the idea of non-absolute space that his theories prompted, however, as they did not agree with his idea of an absolute God. Newton also believed in absolute time; neither space nor time are now considered as absolute. Though Einstein's later general theory of relativity was shown to be more accurate at predicting the exact movements of the stars, Newton's laws are simpler and still accurate enough for daily applications. Newton was also Lucasian Professor of Mathematics at Cambridge University, as was Stephen Hawking much later.

Albert Einstein – Einstein is perhaps most famous for his equation E = mc2. Once an unknown clerk in the Swiss patent office, Einstein first came to be known among the scientific community by writing a paper in 1905 that stated there was no need for the idea of an ether that filled the universe as long as one accepted that time is not absolute. His became the theory of relativity—i.e. the notion that the laws of physics and speed of light are the same for all observers. He also put forward the theory of a cosmological constant, a sort of anti-gravity force which would hold the universe in place, but Edwin Hubble's later discovery the universe is expanding overrode the need for this to make general relativity work. Einstein later called the cosmological constant the greatest mistake of his life. He was also an opponent of quantum mechanics, as he disagreed with the uncertainty principle. In 1935 he worked with Nathan Rosen on the idea of wormholes, called Einstein-Rosen bridges.

Galileo Galilei – Astronomer Galileo had backed Nicholas Copernicus's idea that the sun was at the center of the universe and that the planets, including the earth, all orbited it. This contradicted the Catholic Church's traditional teaching that the earth was at the center of everything and everything orbited it, which did not go down well. In 1609, Galileo used the newly invented telescope and demonstrated that moons orbited Jupiter, thus proving the earth wasn't at the center of everything. He also showed that all objects fall at the same speed, regardless of their weight. He rolled differently sized balls down a slope and measured their acceleration. It was the first time anyone had thought to actually test this. Sir Isaac Newton used Galileo's measurements in his own work. Stephen Hawking said he feels connected to Galileo, as he was born 300 years to the day after the astronomer's death.

Edwin Hubble – In 1924, American astronomer Hubble showed that our galaxy is not the only one. He calculated the distances between numerous galaxies, and in the process discovered the red shift—meaning light from distant galaxies was on the red end of the light spectrum, and as such must be moving away from us. In 1929 Hubble changed everyone's understanding of the universe for good by revealing that the universe is expanding, and therefore that it could have all started off in one place—thus creating the idea of the big bang. This meant Einstein's idea of a cosmological constant, or a kind of anti-gravity force, was inaccurate.

God – Yet to be proven by science, God appears frequently in *A Brief History of Time*, largely in the places where science does not yet have an answer. Stephen Hawking often considers whether God would fit into various models of the universe. For example, there is lots of room for an omnipotent creator in the big bang theory, but less so in a universe that has no boundaries, and therefore no beginning. He also suggests that even lay people could understand the mind of God if scientists answer all the questions of how and why the universe came to be the way it is.

Lay People – Stephen Hawking often refers to the importance of helping the lay person understand great scientific theories, as all of humanity is absorbed with the same line of questioning: why and how are we here? He suggests that once all scientific laws are understood, they will sooner or later also be taught to and understood by everyone, and then we can have the real discussions about the meaning of life. Once that question is answered, he suggests, humanity will "know the mind of God."

Nicolas Copernicus – A Polish priest, Copernicus suggested a simpler model of the universe in 1514, when he argued that the planets, including the earth, orbit the sun. Previously, it has been thought the earth was at the center of the universe, as per the teachings of Aristotle, Ptolemy, and the church. He published his work anonymously to avoid being called a heretic.

Werner Heisenberg – In 1926, German scientist Heisenberg became famous for his uncertainty principle. The idea is that there is inherent uncertainty to all particles' positions, and particles can act like waves, with a wider possible area of location. The impact of this discovery led to Heisenberg's creation of quantum mechanics with Erwin Schrödinger and Paul Dirac in the 1920s.

Alexander Friedmann – A Russian physicist and mathematician, Friedmann made two assumptions about the universe in 1922: first, that is looks roughly the same in every direction, and second, this should be true from wherever one looks. These ideas suggested that the universe is not static, as Albert Einstein was arguing at the time. He predicted what Edwin Hubble later found—that the universe is expanding. Even so, Friedmann's work was not widely known in the West until the 1930s. Arno Penzias and Robert Wilson's discovery of the homogeneity of background microwave radiation throughout the universe proved Friedmann's ideas. Later, Friedmann models were used to explore what the universe might have looked like in its early stages.

Arno Penzias and Robert Wilson – When testing a new, very sensitive microwave detector in 1965 at the Bell Telephone Laboratories in New Jersey, Penzias and Wilson discovered that the universe gives off a uniform level of background microwave radiation. This confirmed Alexander Friedmann'sidea that the universe looks the same in every direction, as well as suggestions that light from the early universe should be so red-shifted that it would now be detected only as microwave radiation. Penzias and Wilson won the **Nobel Prize** in 1978 for their findings.

Roger Penrose – Penrose is a British mathematician and physicist who worked with Stephen Hawking on many matters relating to the general theory of relativity, black holes, and other areas of theoretical physics. In 1965 he showed that a collapsing star would collapse into infinite density in zero space—into something called a singularity. Working together, the two produced a paper in 1970 that stated there must have been a big bang singularity. With John Wheeler, he showed that all black holes must be spherical. He discussed with Hawking his idea that the black hole's event horizon was also its area.

Subrahmanyan Chandrasekhar – Chandrasekhar traveled from India to Cambridge in 1928 to study under Sir Arthur Eddington, who was an expert on general relativity. While on his voyage to England, he calculated how stars would collapse according to their mass. Eddington disliked the idea and talked Chandrasekhar out of it. But when Chandrasekhar won the **Nobel Prize** in 1983, it was partially for discovering this Chandrasekhar limit.

Jacob Bekenstein – A research student at Princeton, Bekenstein suggested a black hole's event horizon area was a measure of its entropy, or disorder. That, in turn, would mean that black holes must emit energy, though they previously weren't thought to emit anything at all. Stephen Hawking disagreed with this theory and was annoyed when, by his own calculations, he realized it must be true (especially given that he had already published a paper about how the theory could not be true). Later, Hawking accepted Bekenstein's theory, illustrating an example of the importance of humility.

Marquis de Laplace – The French scientist argued that the entire universe could be determined by the laws of science. He thought that by knowing scientific laws thoroughly, and where every single particle was in one point in time, scientists would be able to predict everything, even human behavior. This was later undermined by the uncertainty principle, which asserts that one cannot know the position of particles precisely. At the turn of the 19th century Laplace suggested the existence of black holes, but later seemed to abandon the idea. Hawking does not mock Laplace's desire to understand the world, though he does serve as an example of the dangers of misplaced enthusiasm or arrogance.

Sir Arthur Eddington – Eddington was a British astronomer based at Cambridge University who was an expert on general relativity. He was Subrahmanyan Chandrasekhar's supervisor, but disliked his ideas on stars collapsing to zero size and convinced him to abandon that line of research. Eddington was known as being only one of two people who really understood general relativity in his time. He opposed the idea of black holes even when they late became more widely accepted, which Hawking uses as an example of how not to approach scientific mistakes.

Aristotle – An Ancient Greek philosopher, Aristotle believed the earth was stationary and sat at the center of the solar system with the sun and other planets orbiting it. He thought the world and everything in it has always existed, and was made up of earth, wind, fire, and water. He also believed everything was naturally stationary, unless some force propelled it to move, as well as in the idea of absolute time. For the most part, Aristotle represents the follies of unscientific approaches to understanding the universe. Even so, he did work out from pure logic that the earth is round.

MINOR CHARACTERS

Richard Feynman – Feynman was an American physicist who created the sum over histories idea. He said a particle doesn't have one specific history, but rather all possible histories. This changed the way scientists approach studying the history of the universe.

Max Planck – This German scientist suggested that waves, such as light, are always emitted in certain amounts, called quanta, and never randomly. The implications this had on measuring the exact position or velocity of a particle led Werner Heisenberg to discover the uncertainty principle.

TERMS

Absolute space/time – The ideas of absolute space and time came to the forefront of scientific debate only when challenged. **Sir Isaac Newton**'s laws of motion suggested that space was not absolute because objects do not have a natural state of rest. If all objects are in motion, one way or another, that leaves no stable point to measure space against, and also means that space is relative for every observer, with reference to their own position and velocity. The same was later found to be true for time, after it was discovered that light has a fixed speed. Time is not absolute because of the effects of gravity, which draws energy from all particles and waves as they resist its attractive force. The concept of the new arena of activity that has no absolute space or time is called space-time.

Anthropic principle – This philosophical principle arose in response to the question of why the conditions in the universe are just right to support life—whether it is sheer coincidence, or whether the universe has developed specifically to be observed by intelligent beings. Essentially, the principle states, "We see the universe the way it is because we exist." The weak version of the principle argues that certain regions of space will be conducive to forming intelligent life, and of course those intelligent beings will always wonder why their particular region of the universe has life; essentially, if human beings didn't exist, we couldn't wonder *why* we exist. The strong version of the argument states there could be different regions of the universe or even different universes with differing laws of science of different beginnings. Most of these regions or other universes would not have conditions or scientific laws able to create life, but those that *do* seem fine-tuned to support life, leaving room for Creator theories. In essence, Hawking states, "the strong anthropic principle would claim that this whole vast construction exists simply for our sake."

Anti-particle – Each particle has its matching antiparticle. When the two collide, they annihilate each other—in the process creating energy that is then emitted into the universe.

Arrows of time – **Stephen Hawking** suggests there are three arrows of time. First, there is the thermodynamic arrow, which relates to entropy. This arrow points in the direction of disorder increasing—for example, whole glasses smashing into pieces, rather than smashed glasses forming into whole ones. The psychological arrow of time relates to the thermodynamic arrow as our memories form in the same direction of growing disorder. While our brain, or a computer's, may become more ordered with the creation of memories, that order is outweighed by the heat, a disordered form of energy, emitted into the universe during the process. These two arrows always point in the same direction. The third arrow is the cosmological arrow of time, which is the direction the universe is expanding or contracting, meaning that arrow is not always pointing the same way as the other two.

Atom – The base component of matter, comprising a nucleus of neutrons and protons, which is orbited by electrons. The electromagnetic force holds the particles in the atom together.

Big bang – The big bang theory first came into being after **Edwin Hubble** discovered that all galaxies everywhere are rapidly moving away from one another. This means all matter most likely started off all in one place, before expanding rapidly in all directions. This point is called a singularity, where matter is compressed into infinite density in a space of zero size. Some people also believe there will be a corresponding big crunch when the universe collapses back in on itself.

Black hole – A black hole is a localized singularity that forms from a collapsing star. Once the star uses up its fuel, its spent energy is not enough to balance its own gravity, and it begins to collapse in on itself. When it is dense enough, its gravity is so strong that even light cannot escape its pull, and the boundary from which light cannot escape is called the singularity's event horizon. **Jacob Bekenstein** suggested this event horizon is a measure of the black hole's entropy, meaning that black holes ought to emit radiation because entropy should always be increasing, which also led to the realization they must shine, although we cannot see them. Black holes themselves cannot be directly observed, though scientists can observe their effects on surrounding material.

Chandrasekhar limit – **Subrahmanyan Chandrasekhar** found the limit at which a star's mass is too big for it to stabilize after it runs out of fuel. If the star is bigger than this limit, it will collapse under its own gravity and become a black hole.

Cosmological constant – First created by **Albert Einstein** to make his theory of relativity work within a static universe, this was considered a kind of anti-gravity force that would hold everything together. When the theory of a cosmological constant was proven to be defunct, Einstein considered it the worst mistake of his life.

Electromagnetic force – One of the four main types of forces in the universe, electromagnetism draws electrically charged particles toward or away from one another according to their charge. There are positive, neutral, and negatives charges. The electromagnetic force is much stronger than gravity, but not as strong as the strong nuclear force. The electromagnetic force causes the negatively charged electrons in an atom to orbit the positively charged protons.

Electron – A negatively charged particle that orbits the nucleus of an atom. Electrons stay on fixed orbits due according to their wavelengths.

Entropy – The second law of thermodynamics states that disorder, or entropy, tends to increase in any isolated system. For example, a box with a divide in the middle could have oxygen on one side and nitrogen on the other. It is in an ordered state. If the divide is removed, however, the particles will tend to mix and occupy both sides of the box, a disordered state with higher entropy. This is not a definite outcome, but according to the laws of thermodynamics is overwhelmingly likely.

Ether – When people still thought space was absolute—that is, that every observer anywhere could measure space in the same way regardless of their position or velocity— they needed to explain what light traveled through so that all observers' measurements of its speed would be the same. They thought there was an ether everywhere in the universe, even in empty space, that light and other waves traveled through. **Albert Einstein** pointed out this wasn't necessary if people got rid of the concept of absolute time.

Event horizon – The event horizon is the boundary of a black hole at which light, or anything else, cannot escape its gravitational pull. This is why why we cannot see black holes even though they glow. **Jacob Bekenstein** first put forward the idea that the area of the event horizon is a measure of the black hole's entropy.

Friedmann model – **Alexander Friedmann** proposed models of the universe based on the idea it is uniform on a large scale and as such should look uniform from any given point. From his work came a variety of different Friedmann models, proposed by many different scientists, which offer suggestions as to the birth and development of the universe on the basis of general relativity.

Graviton – The gravity force-carrying particle with spin 2.

Gravity – First put forward by **Sir Isaac Newton**, the theory of gravity states that all particles have an attractive gravitational force that draws them together. This operates over long distances, and although it is weak, can build up if enough particles have joined together. This is what sets the earth in orbit around the sun and causes large stars to collapse in on themselves. It is considered one of the four main types of energy.

Imaginary numbers/time – If real numbers run on a left to right axis, imaginary numbers run up and down. They allow for negative answers to multiplication, for example -2 times -2 equals 4, but i2 times i2 equals -4. Scientists use these numbers to deal with difficult mathematics where real numbers won't do the job, for example calculating the sum over histories of a particle.

Neutron – A neutrally charged particle in the nucleus of an atom.

Neutron stars – These stars are supported against their own gravity by the exclusion principle between neutrons, so they do not collapse into black holes. They are very small, cold, and dense. Certain kinds are called pulsars because they emit pulses of radio waves.

Newton's laws of motion – **Sir Isaac Newton** overturned **Aristotle**'s idea that matter has a natural state of rest. Instead, he showed that forces act on objects to accelerate or change their velocity, not to start them moving in the first place. This also overturned the idea of space being absolute.

Pauli exclusion principle – Wolfgang Pauli put forward the idea that similar particles cannot be in the same place as one another while moving in the same direction. They repel each other, meaning particles of the same kind will tend to move away from one another, giving the universe structure, rather than letting it all mix up into soup.

Photon – A quantum of light, also seen as a force-carrying particle.

Proton – A positively charged particle in the nucleus of an atom.

Quantum – A quantum is a packet of energy that is always emitted in certain quantities. The rate at which hot bodies, such as stars, lose energy is finite. The higher the frequency of the wave, the greater the energy in each quantum.

Quantum mechanics – A theory of how small particles are formed and act based on the quantum principle (by which energy is emitted in certain packets, or quanta) and the uncertainty principle.

Quark – The most basic building blocks of particles that scientists have found yet. They come in different kinds and "colors," which combine to form the particles in an atom.

Quasars – A region of a galaxy that is collapsing into a large black hole at the center. Also known as quasi-stellar objects, quasars shine brightly before they are sucked into the black hole.

Red shift – **Edwin Hubble** first noticed that the light given off by stars in distant galaxies is shifted toward the red end of the spectrum of light. Red light has a longer wavelength than other colors, indicating these galaxies are moving away from us.

Singularity – A singularity is a space of zero size holding an infinitely dense amount of matter. Black holes are localized singularities. The big bang starts with and the big crunch ends in a singularity. It is possible quantum mechanics will disprove singularities once the theory is successfully integrated with the theory of relativity.

Space-time – The three dimensions of space and the dimension of time come together under the general theory of relativity to create space-time. Events take place on a point in space-time.

Spin – Each particle (or anti-particle) is associated with a spin, which reflects the number of times one needs to turn the particle until it looks the same. For example, a single-headed arrow must complete one complete revolution to look the same, giving it spin 1. A double headed arrow needs to only turn halfway to look the same, giving it spin 2.

String theory – A relatively modern theory, the idea is that particles are not dots in space-time but rather waves of infinitely long, one-dimensional lengths, like strings. These strings can join together and separate but require the existence of 10 or 26 dimensions for the theory to work.

Strong nuclear force – One of the four major types of force, the strong nuclear force creates the particles within an atom by binding together quarks.

Sum over histories – **Richard Feynman** first came up with the idea that particles do not have one history, but rather have every possible history. This means scientists cannot say exactly how a particle traveled from A to B, but by calculating all the possible routes from A to B, they can find the most *likely* one.

Symmetry – The laws of physics can be said to obey certain symmetries. Symmetry C is when the laws for particles are the same as their anti-particles, P is when the laws are the same in the mirror image of any situation, and T is when the laws remain the same if time were reversed.

Theories of Relativity – **Albert Einstein** first suggested the theory of relativity in 1905, which states every observer has their own unique measure of time, though the laws of science and the speed of light are the same for all observers. The later proposed special theory of relativity neglects gravitational effects. Einstein proposed the general theory of relativity in 1915, which is widely used today. It incorporates gravity, not as a force, but as a consequence of the fact space-time is not flat.

Instead, it is curved by mass and energy, and objects take as straight a line as they can as they move through this warped space-time.

Uncertainty principle – **Werner Heisenberg** proposed the uncertainty principle when he found it was impossible to accurately measure the position and velocity of a particle without that examination affecting the particle's position or velocity. To see the position of a particle, you must shine a quantum of light on it, and the more accurately you want to measure it, the shorter the wavelength of the light needs to be. The shorter the wavelength, the higher the energy of the quantum, and as such the more it will knock the particle off its original course. This principle is central to modern understanding of the small-scale structures of the universe.

Unified theory of physics – **Stephen Hawking**'s life's work was to find the unified theory of physics, which would successfully integrate quantum mechanics with the theory of relativity. Many have joined him on this quest, but so far scientists have failed to find the one rule to unlock the remaining mysteries of the universe. Hawking stated this theory must incorporate the sum over histories and uncertainty principles. Once this theory is found, **everyone** will be able to discuss the great existential questions, such as why we are here, and once those are answered, we will know the mind of **God**.

Virtual particle – A particle that is too small to be seen directly but can be detected by its effects on other particles.

Wavelength – Imagine a ripple on a pond—there are peaks and troughs to the wave. The more powerful the ripple, the shorter the gap between the peaks, called the wavelength, and the higher the frequency of the waves. If a trough of one wave meets a peak, or crest, of another, they cancel each other out. In physics, waves, and even particles, move in a similar manner, so studying their wavelength can provide useful information.

Weak nuclear force – One of the four main forces, this is the nuclear force relating to radioactivity and particles of spin ½, which means they look the same only after two turns.

Wormhole First proposed by Albert Einstein and Nathan Rosen in 1935, wormholes are small irregularities in space-time that allow short cuts to far-distant regions of the universe. It could be possible for an advanced civilization to stabilize or create one to allow intergalactic travel, and even time travel.

THEMES

In LitCharts literature guides, each theme gets its own color-coded icon. These icons make it easy to track where the themes occur most prominently throughout the work. If you don't have a color printer, you can still use the icons to track themes in black and white.

THE SEARCH FOR A UNIFYING THEORY OF THE UNIVERSE

Stephen Hawking's central mission in *A Brief History of Time* is to find a unifying scientific theory that will explain the universe itself. This one definitive theory would pull together all the separate theories that scientists have already, under one set of rules that illuminates and predicts how everything in existence works. The book is a chronology of humankind's efforts so far to determine this unifying theory, as well as ongoing work to find the answer to how everything in the universe works. This is a mission Hawking undertakes on the basis of fulfilling humanity's "deepest desire for knowledge," hinting that his quest to find a unifying theory of physics is no less than a quest to find the meaning of life itself.

Hawking argues there is most likely a unified theory of everything because scientists find that strict rules, for example the law of gravity, govern the universe's makeup and movement. If everything is ordered, it follows there is one central key that determines the nature of the entire universe. Hawking writes, "Now, if you believe that the universe is not arbitrary, but is governed by definite laws, you ultimately have to combine the partial theories into a complete unified theory that will describe everything in the universe." The observable world follows strict, predictable rules, meaning all the accurate scientific theories developed should fit together; any contradiction would imply chaos.

So far, scientists have found four forces that relate to and govern all force-particles in the universe. These are: gravitational force, electromagnetic force, the weak nuclear force, and the strong nuclear force. Yet scientists have not found a singular theory that ties these forces together, meaning this unification quest is ongoing. "Ultimately," Hawking writes, "most physicists hope to find a unified theory that will explain all four forces as different aspects of a single force. Indeed, many would say this is the prime goal of physics today." Hawking, then, is not alone in his quest. Rather, hoped-for, central theories motivate scientists around the world.

While finding such a unifying theory might excite physicists, Hawking is not oblivious to the fact this question does not usually occupy a place close to the average person's heart. Hawking admits: "The discovery of a complete unified theory [...] may not aid the survival of our species. It may not even affect our life-style." The average person's everyday life might not change after the conclusion of this epic quest, even if scientists find their long-sought-after goal. This raises the question of whether physicists' efforts and intellect are well-placed or a waste of time in that they don't immediately affect the practical realities of human existence.

Yet Hawking asserts that seeking such answers represents the deepest longing of the human heart. Since ancient times, people have looked to the stars and asked the "big, basic questions" about how and why we exist, and that still hasn't changed. "Today we still yearn to know why we are here and where we came from," Hawking writes. "Humanity's deepest desire for knowledge is justification enough for our continuing quest." Hawking represents his mission as a service to humankind's perpetual longing to know where we come from. Although the lay person might not phrase their inner longing for meaning as the search for the unification of physics, Hawking says that, in fact, both searches are more or less the same.

He further suggests that by finding *how* we came to be here, we might start to understand *why*. Hawking states, "Then we shall all […] be able to take part in the discussion of the question of why it is that we and the universe exist." In finding a unified theory of physics, then, humankind would give itself the ability to perceive and understand the entirety of the universe and to perhaps answer the deepest question of all: the meaning of life. In seeking the key rules that govern the activity of the entire universe, Hawking's quest is essentially to find the tools with which to answer the big questions asked by every person who ever lived, although they perhaps did not realize the answer could be found via theoretical physics. For Hawking, uncovering the secrets of the universe *is* searching for the meaning of life. But, without the unified theory of everything, that reality feels cosmically distant.

HUMAN CURIOSITY AND INGENUITY

The sense of humanity's genius arises repeatedly in Stephen Hawking's *A Brief History of Time*—not only because of the author's own exhaustive knowledge of the universe's inner workings, but also because of the vast array of scientists, philosophers, and even lay people whose inspired "eureka" moments have forever changed the way people perceive the world. The book ranges over millennia, covering the history of humanity's developing comprehension of scientific principles and revealing our inner desire to understand *everything*. For each tiny physical phenomenon that we have stumbled across, such as the rising and setting of the sun, we have asked, "how and why?" This curiosity, the book ultimately suggests, is in a way what makes us human.

Hawking characterizes humans as perpetually inquisitive, always seeking to overcome any intellectual barrier, or even finding new ones on which to focus their curiosity. Despite the distractions of day-to-day life, humans continue to find themselves absorbed by larger questions. For example, Hawking recalls, "one evening in November that year, shortly after the birth of my daughter, Lucy, I started to think about black holes as I was getting into bed." He contrasts the everyday events of going to bed, family relationships, even the slow progress of time from a human perspective with the cosmological concept of black holes, which involves potential infinities of space and time. The human mind, he asserts, is naturally curious and restless.

This is in keeping with Hawking's summation of the gradual development of classical scientific theory. He notes, "The [ancient] Greeks even had a third argument that the earth must be round, for why else does one first see the sails of a ship coming over the horizon, and only later see the hull?" Without the use of any scientific equipment or theories, the ancient Greeks could apply logic to answer questions arising from their observations, uncovering wider truths beyond their current viewpoint.

Another example of human curiosity Hawking provides is of two American scientists— Penzias and Wilson—testing a new microwave detector. Upon finding more background noise than they'd expected, the men conducted multiple rounds of further tests over the course of years. Hawking writes, "Penzias and Wilson had unwittingly stumbled across a remarkably accurate confirmation of Friedmann's first assumption [that the universe looks the same in every direction]." Although this discovery was not their intention, these two physicists' natural curiosity lead them to follow up on an unsolved matter, and ultimately to prove a prior scientific theory. Their application of their discovery, a work of curiosity, illustrates a form of ingenuity particular to humans.

Such is humankind's inquisitiveness that we even question how we came to be an intelligent species able to ask such questions in the first place. The anthropic principle, is a philosophical consideration that, in Hawking's words, states: "The intelligent beings in [certain hospitable] regions should therefore not be surprised if they observe that their locality in the universe satisfies the conditions that are necessary for their existence." Basically, this means people shouldn't be surprised that the current circumstances allow humans to exist, as we are already here. That this particular theory exists shows that humans' curiosity knows no bounds—human curiosity even questions human curiosity's existence.

As Hawking repeatedly states, there are many questions that remain unanswered, and all the theories about the nature of life and the universe so far are just that—theories. As such, human ingenuity will continue to seek out and identify new problems to solve. Humans will continue to ask questions until everything is known: "our goal is nothing less than a complete description of the universe we live in." While Hawking's words refer directly the scientists' search for a unifying theory of everything, he asserts that this quest is a fundamental desire of the human condition.

This search is also just one step in a long quest for yet deeper understanding. "Even once all the scientific answers are found," Hawking says, the next step will be to "take part in the discussion […] of why it is that we and the universe exist. If we find the answer to that, it would be the ultimate triumph of human reason—for then we would know the mind of God." In other words, once humanity knows the how, we can move on to the why—and once we know that, and all questions are answered, we will transcend our current existence. Hawking shows that to be human is to ask how and why. Such curiosity breeds ingenuity, as humankind cannot rest until all the answers to their questions are found. Hawking goes as far as to suggest that once there are no more questions left to seek, we will somehow be more than human, although it will be an entirely human "triumph" to achieve such a feat.

THE DANGER OF STUBBORNNESS

Though human beings have always sought to understand the universe, Stephen Hawking argues in *A Brief History of Time*, people can also refuse to change their previous assumptions when faced with new proposals. Whether from pride, stubbornness, or dogmatic belief, even the most intelligent people have found themselves on the wrong side of scientific history, obstinately dismissing new ideas because they are intellectually, spiritually, or existentially challenging. Hawking shows that curiosity and obstinacy battle within every person—himself included. What is important is to remain objective throughout scientific inquiry, he argues, and to seek only the truth; otherwise one risks falling behind the inevitable tide of humankind's progress.

Despite establishing humanity's innate curiosity, Hawking also makes clear that people can find it difficult to accept new ideas that contradict earlier, accepted notions. For example, after Johannes Kepler discovered that the planets' orbits around the sun were elongated, he considered his finding as "merely an ad hoc hypothesis, and a rather repugnant one at that, because ellipses were clearly less perfect than circles." While his new suggestion worked well according to observations, it did not fit with his idea that magnetic forces caused the orbits. Hawking mocks Kepler's determination to force his preconceived notions of how the universe to fit together, despite the fact they contradicted measurable events. His ironic tone reveals Hawking does not consider such an approach as scientific.

However, Hawking admits he himself has fallen victim to such stubbornness. He opposed research student Jacob Bekenstein's suggestion that a black hole's event horizon could be used to measure its entropy. Later, when finding, to his "surprise and annoyance," his own calculations would support Bekenstein's hypothesis, Hawking didn't want the student to hear about it, simply because he did not like the new idea. Of course, Hawking's respect for scientific inquiry pushed him to finally accept Bekenstein's suggestion. He uses this example to illustrate how even the best and brightest can be guilty of subjective prejudice, revealing stubbornness as an instinctive human reaction at odds with an intellectual approach.

Other scientists in *A Brief History of Time* similarly push back on evidence that contradicts their deeply-held assumptions about the nature of the universe, and it is only by letting go of any assumptions that progress can be made. Einstein, for instance, arrived at his theory of relatively after dismissing the widely-held notion that time is absolute. Yet he made what he considered the biggest error of his career by introducing the idea of a sort of anti-gravity cosmological constant into his calculations that would keep the presumed static universe from collapsing in on itself. Later discoveries revealed the universe to be *expanding*, however—meaning there was no need for the cosmological constant at all.

Though there is an inner tension between humans' rational intelligence and instinctive obstinacy, Hawking thus argues that the overwhelming tide of human ingenuity and inquisitiveness will inevitably push closer to the truth. What's more, Hawking shows that those who fail to catch on to the latest trends in science fall behind: "The Catholic Church had made a bad mistake with Galileo when it tried to lay down the law on a question of science," he writes when discussing his attendance at a 1981 conference at the Vatican. "Now, centuries later, it had decided to invite a number of experts to advise it on cosmology." This suggests, at least initially, that the Church understood that clinging rigidly onto previous theories would not thwart tide of intellectual progress, no matter how influential the group or person might be. Yet despite the apparent fear of falling behind, the Pope still asserted after the conference that the scientists should not "inquire into the big bang itself because that was the moment of Creation and therefore the work of God." While Hawking offers no personal comment on the matter, from the overwhelming thrust of the book's focus on scientific progress coming ever-closer toward the unifying truths, it seems the Pope's hope cannot be fulfilled; one cannot succeed in restraining human curiosity, and obstinance in the face of scientific discovery may lead to irrelevance.

Hawking thus illustrates both the inspired and unreasonable forces at work in the human struggle to understand everything. Both curiosity and obstinacy are natural reactions within the human mind. But, he shows, humans will continue to seek out answers to the big questions, no matter the obstacles in their way—meaning the best course of action is to let go of preconceived notions and get onboard.

SCIENCE AND RELIGION

In *A Brief History of Time*, Stephen Hawking discusses scientific inquiry against the wider background of humanity's search for meaning, in which religion has played a large part. While he represents religion as being increasingly confined to the corners of modern perceptions of the world, primarily occupying the spaces that science cannot yet explain, he does not distain or criticize people's continued belief in the supernatural. Rather, he shows that people's interest in both science and religion is driven by the same desire for understanding. Thus, the two concepts are not necessarily in direct opposition, although tensions of course remain between them. Nevertheless, he shows that religion is becoming increasingly irrelevant in our understanding of the universe, and indeed, even lay people could one day have as exhaustive knowledge of everything as God himself.

While Hawking takes pains to avoid scorning religion, he does show that religious organizations have largely placed themselves on the wrong side of scientific history. In 1514, for instance, Polish priest Nicholas Copernicus proposed a simpler model of the universe which featured the sun in the center, with the earth orbiting it. Hawking notes, "At first, perhaps for fear of being branded a heretic by his church, Copernicus circulated his model anonymously." The punishment for unorthodox teaching could be brutal, characterizing his church as stubborn and unyielding. As such, Hawking argues that religious dogmatism had slowed the progress of scientific discovery. Even in more recent times, Hawking shows, religious leaders have been hesitant to allow science to question traditional teachings: "[The Pope] told us […] we should not inquire into the big bang itself because that was the moment of Creation and therefore the work of God." Yet this is exactly what Hawking has dedicated much of his life's work to, revealing his disagreement with such an approach to life's big questions.

Nevertheless, Hawking has certain sympathies with religion, and never outright scorns the idea of God, because both science and religion are seeking answers to similar questions. Both physicists and religious believers are concerned with the beginning of the universe—essentially the question of where human beings came from. "The beginning of the universe had, of course, been discussed long before this [discussions about an infinite static universe in the mid-1800s]," Hawking writes. "According to a number of early cosmologies and the Jewish/Christian/Muslim tradition, the universe started at a finite, and not very distant, time in the past." While Hawking does not agree with the conclusions drawn by such beliefs and indicates the probable influence of the Ice Age on their calculations, the direct parallel he draws reveals his sympathy with those grappling with the same questions, albeit with different approaches.

Elsewhere, Hawking says explicitly that we cannot throw out the idea of a God just yet: "An expanding universe does not preclude a creator, but it does place limits on when he might have carried out his job!" Under some theories of the universe, there is still room for a creator figure. As such, science is simply getting closer to understanding how God might have carried out the task. Hawking thus reveals he is not an outright atheist and has not totally discounted the possibility of an omnipotent deity.

While Hawking leaves room for religion in his understanding of the universe, he suggests that such beliefs have decreasing influence in modern science and perceptions. In some models of the universe, which Hawking himself has backed, there is no boundary to the universe, thus leaving no room for a creator figure: "The universe would be completely self-contained and not affected by anything outside itself. It would neither be created nor destroyed. It would just BE." While Hawking does not argue this is certain, he does suggest that if humans were to one day prove such a theory, the room left for a creator god in modern science would become ever smaller.

Not only could humans discover there is no basis for a creator theory, they could even become so intimately familiar with the workings of the universe that there would be no desire or need for religious theory at all: "If we find the answer to that [why we and the universe exist], it would be the ultimate triumph of human reason—for then we would know the mind of God." Hawking's point here is that if humans can understand the "mind" of an omnipotent and omniscient being, humans would surely be as powerful. That is, if humans can thoroughly understand the universe and its workings, there is no need for a God figure at all.

While obvious tension exists between science and religion, their rivalry comes from the fact both are approaches to answering similar questions. Hawking makes plenty of room for religious thought in his scientific discussions, even including how a creator god would fit into various models. Ultimately, however, he suggests that humankind will move past its theories of creators and omnipotent beings, as we come closer to total understanding ourselves.

SYMBOLS

Symbols appear in **teal text** throughout the Summary and Analysis sections of this LitChart.

NOBEL PRIZE

Many of the ingenious scientific discoveries Stephen Hawking describes have earned their discoverers Nobel Prizes, a mark of public acceptance and acclaim for their efforts on behalf of humanity. Yet the sometimes ironic tone Hawking uses when discussing these prizes indicates the politics that comes with their conferral. This illustrates how even the scientific community, comprised of highly educated people often focusing on the big existential questions, isn't free from petty rivalries, disagreements, and inaccurate decision-making. As such, Nobel Prizes represent the characteristically human recognition of human achievements—that is, imperfect and open to discussion.

For example, Hawking writes, "Penzias and Wilson were awarded the Nobel Prize in 1978 (which seems a bit hard on Dicke and Peebles, not to mention Gamow!)." Here Hawking refers to Arno Penzias' and Robert Wilson's identification of background microwave radiation that the universe emits fairly uniformly in every direction. They discovered this almost by accident, although once they realized what they might have found, they spent years gathering data. Their earlier work confirmed Bob Dicke's and Jim Peebles' theory, based on a related suggestion made by George Gamow, that light from the furthest reaches of the universe would only now reach us as microwave radiation because of the red shift from the time/distance it has traveled. Thus, while Penzias and Wilson will go down in history for winning the prize, the other three did not receive the same recognition. The Nobel Prize, though likely well-intentioned, thus is a reflection of humanity's limits and ability to err even in the face of its great scientific achievements and knowledge.

QUOTES

Note: all page numbers for the quotes below refer to the Bantam edition of *A Brief History of Time* published in 1988.

Chapter 1 Quotes

"You're very clever, young man, very clever," said the old lady. "But it's turtles all the way down."

Most people would find the picture of our universe as an infinite tower of tortoises rather ridiculous, but why do we think we know better?

Related Themes:

Page Number: 1

Explanation and Analysis

In the opening lines of *A Brief History of Time*, Stephen Hawking tells the story of an old lady challenging a famous scientist in a public lecture he gave about the cosmos. While opening the book on a humorous note, perhaps to reassure the apprehensive lay reader, the story also illustrates Hawking's point that humanity has long been concerned with the make up of the universe, and by extension, humanity's own place within it. Hawking tells his readers from the first page he his going to describe and explain the progress made in answering these important questions, but that he should hopefully offer more useful, and accurate hypotheses.

With this anecdote, Hawking also illustrates humanity's stubbornness to accept new ideas in the first few lines, representing such a mindset as an obstacle that wiser people must overcome.

The Greeks even had a third argument that the earth must be round, for why else does one first see the sails of a ship coming over the horizon, and only later see the hull?

Related Characters: Lay People , Aristotle

Related Themes:

Page Number: 2

Explanation and Analysis

This third argument for a spherical earth follows from two others Aristotle made: the round shadow of the earth on the moon during eclipses, and the changing position of the north star as one travels north or south. This third point shows that everyday people are curious, and capable of applying everyday logic to answer questions about the world. This observation did not require strenuous study or deep familiarity with scientific principles and texts. Instead, Hawking uses this example to show that people everywhere have always looked at physical phenomena, such as the sails of a ship appearing over the horizon first, and have thought "why" and "what does that mean."

Aristotle thought the earth was stationary and that the sun, the moon, the planets, and the stars moved in circular orbits about the earth. He believed this because he felt, for mystical reasons, that the earth was the center of the universe, and that circular motion was the most perfect.

Related Characters: Aristotle

Related Themes:

Page Number: 2

Explanation and Analysis

Hawking does little to hide his disdain for Aristotle's approach as he describes the Greek philosopher's model of the universe, which has now been proven wrong. Aristotle's unscientific approach, based on superstition and prior assumptions, has no place in modern understandings of the universe, Hawking shows. He underlines this by using the words "thought" and "believed," as opposed to how he describes scientists later who "proved" or "demonstrated" various scientific laws and principles. Hawking shows that simply thinking about what the universe might look like is not sufficient. People must channel their curiosity into investigation, from which discovery can emerge.

As far as Kepler was concerned, elliptical orbits were merely an ad hoc hypothesis, and a rather repugnant one at that, because ellipses were clearly less perfect than circles. [...] he could not reconcile them with his idea that the planets were made to orbit the sun by magnetic forces.

Related Characters: Nicolas Copernicus (speaker), Sir Isaac Newton

Related Themes:

Page Number: 4

Explanation and Analysis

Johannes Kepler, a German astronomer, backed Nicholas Copernicus's model of the universe which said the sun sat at the center of the solar system, with everything else, including the earth, orbiting the star. Kepler added his own observation, that these orbits were not perfectly circular. But he didn't like the idea, as Hawking ironically notes, because his preconceived notions meant he preferred the idea of circles. To add insult to injury, he could not explain why these orbits were not circular, which also undermined his theory that magnetism kept the earth in orbit around the sun. Kepler was unable to surmount these obstacles, and Hawking states it wasn't until Sir Isaac Newton put forward the idea of gravity that elliptical orbits were explained. Kepler's example shows how scientists can get held up on the path to discovery because they are too focused on the answers they *want* to work.

It is an interesting reflection on the general climate of thought before the twentieth century that no one had suggested that the universe was expanding or contracting. [...] this may have been due to people's tendency to believe in eternal truths, as well as the comfort they found in the thought that even though they may grow old and die, the universe is eternal and unchanging.

Related Characters: Edwin Hubble, Albert Einstein, Sir Isaac Newton

Related Themes:

Page Number: 6

Explanation and Analysis

Sir Isaac Newton's laws of motion and gravity point to the fact the universe is expanding, or else it would be collapsing under its own gravitational force. Yet even Newton himself did not actually make the jump in logic to see that the universe must be expanding, instead wondering whether the universe was finite or infinite, and whether *this* would stop the universe from collapsing in on itself. Albert Einstein created the idea of a cosmological constant, a kind of anti-gravity force, to try to explain why the universe remained static despite its gravitational force.

The fact that the universe is expanding wasn't discovered until Edwin Hubble stumbled across the idea while measuring the distances to various galaxies. This example shows that even the brightest minds, which have changed the way humans see the universe, can still fail to think outside the box, even when the answer is staring them in the face.

Hawking further links this stubbornness with people's desire to find meaning, often in the form of religion. Thus, their spiritual understanding of the universe becomes irrevocably linked with their own place in it, and therefore their role, fate, or destiny, making it all the harder to reassess principles previously considered certain.

Chapter 2 Quotes

The Aristotelian tradition also held that one could work out all the laws that govern the universe by pure thought: it was not necessary to check by observation. So no one until Galileo bothered to see whether bodies of different weight did in fact fall at different speeds.

Related Characters: Sir Isaac Newton, Galileo Galilei, Aristotle

Related Themes:

Page Number: 15

Explanation and Analysis

Hawking advocates a scientific approach to understanding the universe, which involves finding theories that can make accurate predictions that match observations. To know if these predictions match observations or not, scientists must actually observe the outcomes of experiments. Hawking's use of the word "bothered" in the above quote shows his exasperation with Aristotle and his nonscientific approach. If the Greek philosopher had taken the time to actually check the accuracy of his assertions, he would have been able to better exert his genius to help the progress of humanity's scientific understanding. Galileo's experiments set the ball rolling for Newton's later laws of motion and gravity, which changed the way people understood the basic properties of matter, forces, and the overall universe.

Newton was very worried by this lack of absolute position, or absolute space, as it was called, because it did not accord with his idea of an absolute God. In fact, he refused to accept lack of absolute space, even though it was implied by his laws.

Related Characters: Sir Isaac Newton

Related Themes:

Page Number: 18

Explanation and Analysis

Despite the fact he had already turned science on his head by finding that objects have no property of absolute rest, and instead are always moving, Newton could not accept the next step implied by his own laws of motion. His theological concept of the universe did not agree with the scientific principles he discovered, causing an inner crisis. Hawking uses strong and emotional language to emphasize Newton's dilemma, such as "refuse" and "worried." This was a case of Newton being stubborn and irrational, even though he had previously discovered revolutionary scientific laws. This, Hawking shows, can be one of the restrictive effects of dogmatic belief in certain models of the universe.

Chapter 3 Quotes

Our sun is just an ordinary, average-sized, yellow star, near the inner edge of one of the spiral arms [of a galaxy that is 100,000 light-years across]. We have certainly come a long way since Aristotle and Ptolemy, when we thought that the earth was the center of the universe!

Related Characters: Aristotle

Related Themes:

Page Number: 39

Explanation and Analysis

Aristotle is again the butt of Hawking's jokes, as the physicist shows the great lengths human understanding can advance when embracing an experimental and open-minded approach, unlike the Greek philosopher's logic-first methodology. More poignant is the fact that humanity's curiosity continues to search for answers even when those answers humble the species in a way never before realized. The more that scientists discover, the smaller the influence the earth and its inhabitants are revealed to have over the wider cosmos. Aristotle's "pure logic" star-gazing had aggrandized humanity's perception of itself, while star-*measuring* has unveiled the layout of our galaxy, and many others too. Yet humans, overall, are not deterred by the humbling answers they have found, and continue, including in *A Brief History of Time*, to seek out the ultimate answers to life's big, existential questions.

Many people do not like the idea that time has a beginning, probably because it smacks of divine intervention. (The Catholic Church, on the other hand, seized on the big bang model and in 1951 officially pronounced it to be in accordance with the Bible.)

Related Characters: God , Alexander Friedmann

Related Themes:

Page Number: 49

Explanation and Analysis

Alexander Friedmann's work on the initial potential configurations of the universe, known as Friedmann models, suggested there ought to have been a time when everything was in one place, and the distance between all the matter was zero, which is called a singularity. All this matter then expanded very rapidly, in a process called the big bang. While it was a new, and scientifically-backed idea, this model left lots of room for a Creator figure, something the church grasped at. Ironically, the suggestion saw the church accepting the scientific theory as it agreed with its preconceived notions, while some scientists disliked it purely because it allowed religious interpretations. Neither approach could be said to be truly scientific.

Chapter 4 Quotes

The success of scientific theories [...] led the French scientist the Marquis de Laplace [...] to argue that the universe was completely deterministic. Laplace suggested that there should be a set of scientific laws that would allow us to predict everything that would happen in the universe.

Related Characters: Werner Heisenberg, Marquis de Laplace

Related Themes:

Page Number: 55

Explanation and Analysis

If science could describe the entire make up and position of the universe at one point in time, Laplace argued, even human behavior could be predicted once all the laws of the universe were understood. But later, Werner Heisenberg showed that it was impossible to accurately measure a particle's position and velocity with pinpoint precision—the harder he tried to so so, the higher the energy of the light he had to use, which, in turn, pushed the particle off its original course. Laplace's prediction was proven false, revealing the errors of misplaced arrogance. Still, Hawking does not blame Laplace for seeking a universal theory that will uncover all the workings of the world, as it is the very same thing Hawking himself was searching for in his early career and in this book.

Chapter 5 Quotes

We now know that neither the atoms nor the protons and neutrons within them are indivisible. So the question is: what are the truly elementary particles, the basic building blocks from which everything is made?

Related Themes:

Page Number: 68

Explanation and Analysis

Humans will keep digging for the answers behind the answers. After finding the atom, scientists found the proton and neutron, which form the nucleus of the atom. But that was not far enough. Scientists also found that these smaller particles were composed of quarks, as well as the characteristics of these even smaller particles. This particular search is symptomatic of humanity's deeper longing for a greater understanding of the universe, everything in it, and how it all works. It seems scientists will not stop digging until the final answers, to everything, are found and understood.

Chapter 6 Quotes

The hostility of other scientists, particularly Eddington, his former teacher and the leading authority on the structure of stars, persuaded Chandrasekhar to abandon this line of work [...] However, when he was awarded the Nobel Prize in 1983, it was [...] for his early work on the limiting mass of cold stars.

Related Characters: Albert Einstein, Subrahmanyan Chandrasekhar, Sir Arthur Eddington

Related Themes:

Related Symbols:

Page Number: 87

Explanation and Analysis

Chandrasekhar discovered that if a star was larger than a certain limiting mass, when it ran out of its nuclear fuel it would collapse under the force of its own gravity, becoming a black hole and eventually a singularity—a point of zero size and infinite density. Eddington opposed this finding, as did Albert Einstein, intimidating Chandrasekhar, even though his work was later proven accurate and became widely influential. His Nobel Prize is testament to the fact that correct scientific findings will one day receive public acclamation, in turn showing that opposing scientific progress cannot hold back humanity's advancement for long.

Chapter 7 Quotes

[...] one evening in November that year, shortly after the birth of my daughter, Lucy, I started to think about black holes as I was getting into bed. My disability makes this rather a slow process, so I had plenty of time.

Related Characters: Stephen Hawking

Related Themes:

Page Number: 103

Explanation and Analysis

Hawking contextualizes the birth of one of his first leading theories on black holes within the daily routine of his life, as well as the birth of his daughter. His reference to his physical disability juxtaposes the great agility of his mind, as he describes himself pondering the inner workings of black holes while being assisted into bed. Hawking's humor makes this scene casual, as though it is the most natural thing in the world to think about black holes at bedtime, reflecting how natural it is for the human mind to wonder at the universe. No matter the obstacles, physical or otherwise, the human brain will continue to seek out answers to the complex workings of the universe.

Chapter 8 Quotes

> The Catholic Church had made a bad mistake with Galileo when it tried to lay down the law on a question of science, declaring that the sun went round the earth. Now, centuries later, it had decided to invite a number of experts to advise it on cosmology.

Related Characters: Nicolas Copernicus, Galileo Galilei

Related Themes:

Page Number: 120

Explanation and Analysis

Galileo had backed Nicholas Copernicus's model of the solar system, which stated the earth orbited the sun, as did the other planets. The church's refusal to accept this scientifically-backed model showed a stubbornness that did not last the test of time. Over the centuries, the overwhelming tide of human progress left the Catholic Church behind, and it had to reconsider its position. Hawking describes the church as returning, repentant, to scientists without its previous arrogance, instead seeking answers that scientists and religious believers share in common: both groups wish to deepen their understanding, both of the universe and humanity's place within it.

> The whole history of science has been the gradual realization that events do not happen in an arbitrary manner [...] they reflect a certain underlying order, which may or may not be divinely inspired. [...] There ought to be some principle that picks out [...] one model, to represent our universe.

Related Characters: God

Related Themes:

Page Number: 127

Explanation and Analysis

Scientists have gradually stacked up overlapping layers of understanding that build a wider picture of the universe and how it works. These theories, for the most part, fit together, revealing an inherent order in the workings of the universe. This *could* point to God's work in creation, with the aim of creating a stable world for people to live in. Hawking at no point definitively rules this out, and he certainly does not mock the idea. Regardless of divine intervention or a lack thereof, Hawking reasons that the order observed in the laws of science point toward a unifying theory of physics, and indeed, of everything.

> Most sets of values would give rise to universes that, although they might be very beautiful, would contain no one able to wonder at that beauty.

Related Characters: God

Related Themes:

Page Number: 130

Explanation and Analysis

The "values" Hawking mentions here refer to the precise configuration of the universe that seems almost chosen on purpose for the creation of life. Certain values, such as the charge of an electron, are just within the bounds to allow other processes necessary for life. This could leave room for God as a creator. However, one can also argue the anthropic principle, which states that the universe is the way it is, because if it wasn't, we wouldn't be here to see it. Aside from the discussion of reasons, Hawking's main point, here, is that humans, everywhere, "wonder" at the beauty of the universe. Thus, asking such questions, i.e. those which prompt the anthropic principle in response, comes naturally to people.

> Must we turn to the anthropic principle for an explanation? Was it all just a lucky chance? That would seem a counsel of despair, a negation of all our hopes of understanding the underlying order of the universe.

Related Themes:

Page Number: 137

Explanation and Analysis

Hawking reveals his personal, even emotional, interest in finding a unifying theory that explains how everything in the universe works. The anthropic principle "answers" why intelligent life exists by saying that if the universe did not support intelligent life, humans would not be here asking scientific questions about it. Hawking, it seems, is dissatisfied with this answer. By using the first person plural, "our," he shows the desire to understand the world we live in is not something he alone hopes for. This is an innate, universal human longing not only to understand, but to find a *reason* for it all.

> We don't yet have a complete and consistent theory that combines quantum mechanics and gravity. However, we are fairly certain of some features that such a unified theory should have.

Related Themes:

Page Number: 138

Explanation and Analysis

In the quest for the holy grail of all theories, the unifying theory of physics, which combines the currently incompatible quantum mechanics (which deals with small scale, atomic-level structures) and gravity (which determines the movements and lifecycles of stars), scientists have found fundamental theories that must apply to a theory that incorporates both. Hawking presents this progress as positive evidence that scientists are looking in the right places, as the pieces begin to come together. Hawking's language is full of optimism, evidenced by his noting the unifying theory hasn't been found "yet" and that this mission is not his alone by consistently using "we."

> So long as the universe had a beginning, we could suppose it had a creator. But if the universe is really completely self-contained, having no boundary or edge, it would have neither beginning nor end: it would simply be. What place, then, for a creator?

Related Characters: God

Related Themes:

Page Number: 146

Explanation and Analysis

Hawking puts forward the idea that the universe could be finite in space but not have any edges, like how the earth's two-dimensional surface has no edges. A spaceship could travel round the universe and end up back where it started. But this also rules out a big bang model, as well as any model involving a beginning or end. God, then, is written out of the books in a no boundary model. It could be that after humanity's curiosity finds truths that humble the species, scientists could also find greater laws that override religious beliefs. Hawking leaves this as an open question, as he is unwilling and currently unable to suggest an answer.

Chapter 9 Quotes

> The progress of the human race in understanding the universe has established a small corner of order in an increasingly disordered universe.

Related Themes:

Page Number: 156

Explanation and Analysis

Here, Hawking is directly referring to entropy, the idea that disorder in any isolated system tends to increase. Think of a smashed glass reforming itself— the world does not naturally become more orderly. Even expending energy to create order in one region will create higher overall disorder due to the emission of that (disordered) energy into other regions. Thus, while human understanding is creating a more ordered world on earth, the species' effort creates greater overall disorder. This intrinsic nature of the universe to tend toward disorder contrasts with humanity's progress in understanding the ordered laws that inform that apparent chaos—which, somewhat paradoxically, makes the universe seem a little less disorderly.

Chapter 11 Quotes

> A complete, consistent, unified theory is only the first step: our goal is a complete *understanding* of the events around us, and of our own existence.

Related Themes:

Page Number: 186

Explanation and Analysis

At the end of a chapter detailing the quest for a unified theory of physics, as well as what that theory might look like and what it might accomplish, Hawking finishes by stating that this goal is just another step on a much more significant mission. By finding this so-called unified theory, humankind will have equipped itself to truly examine the universe and its constituent parts, humankind included. The unified theory is not an end-goal in itself, but a tool to answering the existential questions that have stayed with curious humans since the earliest days, such as how and why intelligent life came to exist.

Chapter 12 Quotes

Even if there is only one possible unified theory, it is just a set of rules and equations. What is it that breathes fire into the equations and makes a universe for them to describe? [...] Why does the universe go to all the bother of existing?

Related Characters: God

Related Themes:

Page Number: 190

Explanation and Analysis

Hawking uses a list questions to emphasize his point, reflecting that the search for a unifying theory of physics was born out of humanity's endless questioning of the universe and existence. These are questions that will not go away until humans find the answers. Even after finding the theory, if possible, then comes the next set of questions. Hawking demonstrates humanity's deep-seated, age-old desire to find *all* the answers, and suggests that such a day could still be very far off. The unspoken question is whether it is God that breathes life, or "fire," into the universe, as this language draws on Biblical phrasing. This subject, it seems, will be left until the very end of humanity's line of questioning.

[...] if we do discover a complete theory [...] Then we shall all [...] be able to [discuss] why it is that we and the universe exist. If we find the answer to that, it would be the ultimate triumph of human reason—for then we would know the mind of God.

Related Characters: Lay People , God

Related Themes:

Page Number: 191

Explanation and Analysis

In his poignant closing remarks in the very last lines of *A Brief History of Time*, Hawking discloses what lies at the end of the mission to find the unifying theory of everything. It is not simply about knowing *how* everything works, but knowing *why*—that is, perhaps, understanding the mind of the creator that made it all. His poetic turn of phrase shows that Hawking does not discount God as a potential answer to all of humanity's questions. However, Hawking also allows room for humanity's understanding to supplant the role of a creator, suggesting that with total understanding` humankind could also become omniscient (all knowing) and maybe even omnipotent (all powerful).

Also, it is notable that this mission and realization applies to everyone, everywhere. Hawking emphasizes that all of humanity asks question about why we exist, and that everyone *should* be part of that discussion—one of his reasons, it seems, for writing the book in the first place.

SUMMARY AND ANALYSIS

The color-coded icons under each analysis entry make it easy to track where the themes occur most prominently throughout the work. Each icon corresponds to one of the themes explained in the Themes section of this LitChart.

CHAPTER 1

When a famous scientist (possibly Bertrand Russell) gave a public astronomy lecture, he described the orbits of the planets in the solar system and how the sun orbits the center of our galaxy. After he finished, an old lady at the back told him he was talking nonsense, as the world is flat and sits on the back of a tortoise. When he asked what the tortoise stands on, she replied it is tortoises all the way down.

Hawking opens his book about mankind's great scientific progress to date with an anecdote of a stubborn old lady who is determined to hang on to her superstitions despite informed individuals' best attempts to help her access the latest understanding of the universe's make up. Some people, it seems, just can't be taught—but Hawking shows he's going to try anyway.

Although the old lady's image is ridiculous, do scientists really know better? New technologies are helping to offer answers to age-old questions about the universe and where humans came from. Maybe one day the answers will seem as obvious as the earth's orbit, or as ridiculous as the image of the tortoises. Time (whatever it is) will tell.

Hawking does not side with the old lady, but he does stop to ask how it is that scientists can say they have better ideas than she does. Just stating a worldview does not mean that it is correct. This comparison shows that all people long to understand the universe and humanity's place in it.

Greek philosopher Aristotle gave two good arguments for the earth being a sphere instead of flat. First, a lunar eclipse must be the earth blocking the sun's light, and the shadow is always round, not elongated as it would be if the earth was flat. Second, the Greeks saw that the North Star (which lies over the North Pole) is more central in the sky the further north you sail, and closer to the equator the further south you travel. From this, Aristotle could even make an educated guess about the distance around the earth. Another point the Greeks noticed is that when ships came over the horizon, one always sees the sails first, and later the hull.

Famed classical philosopher Aristotle could apply logic to everyday phenomena, such as the position of the north star, to deduce that the earth was round. This did not require deep scientific knowledge, but simply using logic to follow up his curiosity. This was true not only for Aristotle but also for his compatriots, showing that curiosity about the world is not confined to intellectuals. Everyone has questions about why the world works the way it does; it is a natural part of being human.

Yet Aristotle believed the earth was fixed in place at the center of the universe, and all the other heavenly bodies moved around it in perfect circular orbits. Ptolemy took this idea further in the 2nd century AD, creating a cosmological model consisting of eight spheres—one for the moon, sun, stars, and the five known planets. Each moved on their own complicated paths in these spheres while the fixed stars remained in the same formation at the outer limit, rotating together across the sky. Anything beyond that limit was unknown.

Even the wise Aristotle could not see past his own biases. While he could accept that the earth was round, he could not overcome his baseless conviction that the earth was at the center of the universe. Ptolemy, a multispecialist Greco-Roman thinker, had the same stubbornnes, and created an overly complex model to fit previous assumptions.

Ptolemy's model could fairly accurately predict the movement of each heavenly body. But for it to be correct, the moon would have to pass by the earth twice as close as normal every now and then, something that bugged Ptolemy, as it ought to have appeared twice as big as normal at those times. But the model was generally accepted anyway, including by the Christian church, as there was lots of space outside the model for heaven and hell.

Ptolemy directly overlooked obvious flaws in his model because he was determined to prove his own ideas were correct. His ideas were popular because they agreed with how people saw the world, and their place in it. They did not challenge the church or its teachings, so the model was easily accepted.

Nicholas Copernicus, a Polish priest, proposed a simpler model in 1514, publishing anonymously at first to avoid being called a heretic. It took nearly a century for his idea, that the sun sat stationary at the center of the planets, to be taken seriously. German astronomer Johannes Kepler and Italian Galileo Galilei backed his theory, even though it was not perfect based on the observable movements in the cosmos.

Copernicus, working in anonymity for fear of reprisals from an obstinate church, discovered a truth that was too important to ignore. The fact that it took decades for his work to be respected demonstrates the difficulties scientists can face when promoting new ideas. Nevertheless, because of the accuracy of his model, the idea finally stuck.

The final blow came to the ancient model with the invention of the telescope. Galileo observed Jupiter and found it had several satellites, meaning not everything orbited the earth. Those moons could still primarily orbit the earth and have very complicated journeys that also cause them to appear to orbit Jupiter—but Copernicus's idea was simpler. Kepler added the idea that orbits could be elongated, not perfectly circular, and finally the theory worked with the observable movement of the heavenly bodies.

Galileo offered clear and simple evidence that backed Copernicus's model, showing that the truth will out when it comes to matters of science. The key here is that Galileo and Kepler could match their models with what was actually observed. Ptolemy, in contrast, had seen the moon move in ways contrary to what his model suggested, but did not adapt his ideas—a critical failure.

Kepler didn't like the idea of elliptical (elongated) orbits as much as perfect circles, but the theory seemed to work well in practice. Now the problem was that this didn't seem to work with the idea that magnetic forces controlled all this movement. It wasn't until Sir Isaac Newton's *Philosophiae Naturalis Principia Mathematica* came out in 1687 that an explanation was offered.

Although he had earlier backed a relatively new idea, that the earth orbited the sun, Kepler still could not let go of his assumption that magnetic forces drove the movement of the heavenly bodies. Even the best and brightest, who can see the errors in others' judgment, cannot be as objective with their own work.

Newton's work offered the math to back up his ideas about how things move in space and time. His law of universal gravitation suggested everything is attracted to everything else, with the force being stronger when those things are closer together and bigger. That's why things fall to the ground. Newton mentioned the idea coming to him as an apple fell to the ground, though the idea that the apple hit him on the head was probably added by others later. Regardless, his theory showed the moon moves in an elliptical orbit around the earth, while the planets have an elliptical orbit around the sun.

Newton created his laws on the basis of two crucial foundations: evidence and observation. He explained, mathematically, why apples fall to the ground and why the planets' orbits are not perfectly circular, the latter being an idea that obsessed Aristotle and Kepler, blinding them from the path to greater progress.

The idea of a natural boundary to the universe was thrown out along with Ptolemy's celestial spheres, replaced with the Copernican model. Thus, the new assumption was that the fixed stars were not so fixed after all, but very far away and hard to measure. In fact, given his idea of gravity, these stars should all be moving around each other, and at some point should fall together. If there are finite stars in a finite universe, the stars would fall into each other, Newton wrote in a letter to a friend in 1691. But infinite stars spread uniformly across an infinite universe would not, as there would be no center, he reasoned.

Newton's revolutionary discovery of gravity, however, only led to more questions. If every star and planet was attracting every other star and planet, the universe ought to be collapsing in on itself. Newton was unsure how to account for this, as the law of gravity seemed correct in and of itself. He focused on the question of whether the universe was finite or infinite to try to get to the bottom of this quandry.

This is one of many snares when talking about the infinite. In an infinite universe every point is the center because every point has infinite stars either side. These days, it is now thought the finite model must be correct. Adding more stars beyond the limit of that boundary (i.e. picturing a bigger universe with more stars) makes no difference—all the stars will still fall in on each other at the same pace. It is now known there cannot be a model of an infinite universe where all the bodies are always attracting each other.

Newton was following the wrong path to try to solve the problems his laws seemed to raise, but Hawking does not present him as stubbornly sticking to unfounded assumptions. He was tackling new concepts, and it is always easier to make judgments in hindsight, with knowledge of centuries of subsequent scientists' work.

Before the twentieth century, no one had suggested the universe was expanding or contracting, which reveals the way people were thinking back then. Everyone either thought the universe had always existed in its current state, or that it was created at a certain point in the same state it is now. This could have been because of people's belief in eternal truths, or perhaps the comfort of the idea of an unchanging universe, eternal even after their own deaths.

The time it took for humanity to notice that the universe is expanding shows the deep, inbuilt stubborness people must overcome to see through their assumptions, especially because it is hard to realize that they are assumptions in the first place. It had simply never occurred to anyone that the universe was not static. This illustrates people's way of thinking, as the form of the universe implies humanity's role within it. Up-ending one's understanding of the world has direct implications for one's sense of self, and one's destiny.

Even though Newton's theory showed that the universe was not static, people did not immediately consider that it might be expanding. Instead they toyed with the idea that at great distances gravity could be repulsive, rather than attractive. It allowed the stars to remain in equilibrium. But now such a model is considered unstable, as movements in either direction would create increasingly strong repulsive or attractive forces.

Newton and his contemporaries could not see what they could not see. Unaware of their own inflexible perspective, they again tried to manipulate the theory of gravity into their preconceived image of the universe. Their attempts simply would not work, because they were not correct. Yet this offers further evidence that humanity will continue to ask more questions even after new answers come to light.

German philosopher Heinrich Olbers wrote in 1823 that in an infinite static universe, every line of sight would end on a star. Others had made similar arguments, even at the same time as Newton, but Olbers's objection to Newton's concept of an infinite, static universe was the first to be widely noted. Thus, the night sky ought to be as bright as daylight. The only way to explain the night sky was that each star was created at a finite time. If so, the light from those stars might not have reached us yet. But this, in turn, raised the question of when the stars came to be.

Olbers reasoned, scientifically, that the universe must be finite, answering Newton's previous question. But, as ever, this only raised more questions. If the world is finite, and the stars had not been around forever, the question now was when they began. Olbers took prior knowledge and applied it to observation to draw logical conclusions. He was one in a long line of people to do so, who together create the history of scientific progress.

The idea of a beginning to the universe was not new. Religious thought had already put the beginning at a not too distant time in the past. One line of reasoning for the beginning was a "First Cause," which caused everything else in a connected line of causality. St. Augustine put Creation—as per the book of Genesis in the Bible—at around 5,000 BC. That's not that far off the end of the last Ice Age in around 10,000 BC, when civilization took off.

Every civilization has been curious about the universe and humanity's place in it. One key subject in that discussion is how this all came to be. As such, religious and scientific thinkers all deal with the same topics, albeit approaching the matter from different angles. Nevertheless, Hawking consistently places the scientific approach in a higher position than any other.

But Greek philosophers, including Aristotle, did not like the idea of a beginning because it sounded like divine intervention. They thought people and the world had existed and will exist forever. They had also considered the ideas of cultural and scientific progress toward greater understanding, but argued that large disasters had always put the human race back to square one.

Aristotle and his counterparts saw civilization as cyclical—catastrophic natural disasters would reset humanity's progress, and the cultural and scientific machines would start back up again, endlessly. This contrasted with viewpoints such as St. Augustine's, which reasoned the progress we see shows time is linear. Yet Hawking suggests the Greek philosophers discounted the idea of a beginning simply because it did not agree with their ideas about religion, rather than objectively looking for an answer.

Philosopher Immanuel Kant later considered the question of whether the universe had a beginning in time and if it is limited in space, in his *Critique of Pure Reason*, published in 1781. He called the questions antinomies, meaning contradictions, of pure reason, because both ideas—that the universe had a beginning, and was eternal—had compelling arguments.

Kant took a similar approach to Aristotle, by seeking answers to questions about the universe by applying logic. He found, essentially, that one could reason either case just as logically. Hawking uses this example to show the limited success that logic can achieve—ultimately, one must apply that logic to observation to prove a point.

Kant reasoned that if the universe did not have a beginning, the time before any event was infinite, which seems ridiculous. If the universe started at a particular time, the time before that was infinite, so why would it start at any specific time. Both arguments are really the same—they assume time moves back forever, whether or not the universe exists. But really, the concept of time itself did not exist before the beginning. This is an idea St. Augustine used, when asked what God did before the beginning. He stated time is a concept only within Creation, and did not exist before it.

Hawking describes, and criticizes, Kant's work to illustrate another approach humans take to understanding the universe. Hawking shows again that religious and scientific thought are not mutually exclusive. St. Augustine was on the right track when he said that time is a property of the universe, and so has no meaning or bearing before any beginning. This is something Kant did not grasp, though he was asking the right questions.

The question of the beginning was largely related to metaphysics or theology back when everyone thought of the world as static and unchanging. The world looked much the same from both ends of the argument. That changed in 1929 when Edwin Hubble saw that all distant galaxies are moving rapidly away from each other. As such, at some point, possibly 10 billion to 20 billion years ago, all the matter in the universe must have been in one tiny place of zero size, meaning the density of the universe was infinite. This realization made the question of beginnings one about science.

Hubble's landmark discovery that every galaxy in every direction is rapidly moving away from every other galaxy turned the question of beginnings on its head. The idea suggested a definite point in time and space where everything came into being. Now that a better model for the universe had been found, the question became how to measure its history—to understand how the universe came into its current state and where it was heading. It was no longer a matter of theologizing, but calculating.

Hubble's discovery created the idea of the big bang, a time when the universe was tiny and infinitely dense before rapidly expanding. At that time, all laws of science would break down, meaning time had its beginning in the big bang, because any previous times would no longer have any bearing.

The big bang agrees with St. Augustine's argument that time is purely a property of the universe and has no meaning outside its boundary in space and time. Anything that existed or happened before would have no effect on anything existing or happening now.

This new idea of the creation of time is completely different to any that preceded it. In an unchanging universe, some outside power determines the start, and there is no physical need for a beginning. But if the universe is expanding there could be physical reasons behind the need for a beginning. An expanding universe does not rule out the existence or involvement of God, but it does determine when time started.

The big bang does not place religion and science at opposite ends of possibility. But understanding more about the physics of a beginning does complicate the idea of God creating the world. This shows that understanding the "how" can sideline God, in turn showing that humans use deities to explain what they do now yet know.

To discuss all these questions, first one needs to know what a scientific theory is. A theory is a model of the universe, or one part of it, and rules that link aspects of that model to what we can observe. It exists only in our minds (whatever that means). Theories are good if they can explain observations with a few factors, and can accurately predict outcomes in future observations. For example, Empedocles's idea that the four elements were earth, air, fire, and water is simple, but cannot make any predictions. By contrast, Newton's theory of gravity, which is determined by mass and distance, is even simpler, but can accurately predict the movements of the stars.

Hawking definitively states the specific characteristics of the modern scientific approach to differentiate it from the others outlined previously. Ideally, scientists should be objective and results-focused. This should rule out personal agenda, ego, or stubbornness. The focus is on finding the laws that govern the world, not finding complicated mechanisms by which one's assumptions can be transplanted onto reality.

Any physical theory cannot be proved entirely. Even if every test has backed up the theory so far, one cannot prove that the next test will not disprove it. Even one single piece of evidence contradicting the theory can disprove it. Philosopher of science Karl Popper said that confidence in any theory grows with each accurate prediction, but that theory must be cast aside or adapted if even one test outcome or observation contradicts it. (Although in reality, one can always question the competence of the observer.)

Scientists must be totally objective, ready to drop or adjust any theory where it does not match observations. This is a stark contrast from the earlier approaches Hawking outlined. No worldview is considered absolute or untouchable. Everything can change in an instant.

Usually, new theories are largely extensions of previous theories. For example, Mercury's movement diverged slightly from predictions made by applying Newton's law of gravity. Albert Einstein's slightly different prediction, via his general theory of relativity, matched with what was seen, a critical confirmation of his new theory. Newton's theory is still used in most cases, as the differences are so tiny and no difference is visible in day-to-day usage. Newton's theory is also much simpler to use.

Theories build on other theories, or adjust previous theories, to gradually build up an ever-more accurate and dependable set of laws with which to measure and assess the universe. Yet, as is shown by the continued use of Newton's less precise theory, different theories can fit different uses, revealing a patchwork of ideas and rules available for understanding the universe.

Science's ultimate goal is to offer one theory for the entire universe—a theory of everything. But usually scientists deal with it in one of two ways. First, they apply the laws that explain how things move through time to make predictions. Second, there is the question of the initial state of the universe. Some think only the first question is strictly science; the second is metaphysical or do to with religion. They say God can do whatever he likes. While that could be true, he made the universe in a way that is governed by certain laws, meaning there are also laws determining the beginning.

Hawking introduces a key theme of this book and of modern scientific endeavor: the hunt for a unifying theory of everything. The idea is that one set of rules can explain how the universe came to be and how it all works. People approach this question from different angles, and indeed religion represents one such approach. The main point is to keep asking questions, as the universe can be understood.

It is tricky to offer one theory for the whole universe right now. Instead there are numerous partial theories. This could be the wrong approach. If everything in the universe fundamentally depends on everything else, only looking at certain parts cannot reveal the whole picture. But, that is how progress has been made so far. For example, gravity depends only on mass, not the content of an object, so we do not need a theory on the construction of the sun to predict its movement.

All the progress made so far is contributing to this mission to find one unifying theory, whether intentionally or not. While not ideal, according to Hawking, these partial theories have brought a certain degree of progress, and have individual worth.

Scientists now describe the universe in terms of the general theory of relativity and quantum mechanics—both great achievements of the first half of the 20th century. The first relates to gravity and large to really large-scale structures of the universe. The second relates to miniscule matter a billionth of an inch wide. But, the two do not relate and cannot both be correct. What is needed is a quantum theory of gravity, but it might be some time until we have one. Many of the aspects and predictions of that theory are already known, though.

Hawking sets out the two key theories that the book will address, as well as the fact the next great step in finding a unifying theory is to unify these central concepts. Scientists have discovered truths about the largest and smallest structures in the universe, and now the task is to find how these can be used together to answer the last remaining questions.

If the universe is not chaotic, but rather is governed by laws, all the partial theories must fit into one overarching theory of everything. But there is a fundamental contradiction in that search. We've assumed so far that we are rational beings that can know the world, which would mean we can progress to such knowledge. But if there really is such a theory, it would determine our own actions too, meaning the theory would determine its own discovery. Why would discovery be the ultimate conclusion, rather than a wrong conclusion, or no conclusion?

As Hawking has already shown, science shares many borders and overlaps with philosophy. If this unified theory really could predict everything, that would include human behavior and intelligence, meaning the theory would predict its own discovery. So, the question Hawking posits is whether the theory would necessitate its own discovery.

Charles Darwin's theory of natural selection might offer an answer. He stated that genetic differences occur in any group of self-reproducing beings, and that certain differences will result in strengths that cause those beings to be more likely to survive. So far in history, intelligence and science have indicated a survival advantage. Today, our discoveries could well kill us all. Also, a unified theory might not affect our likelihood of survival. But, given the regular evolution of the universe, our logical reasoning as developed by natural selection means we should be able to make the right conclusions.

Hawking reveals his optimism that humanity can and will uncover a unified theory of everything. Although it might not directly improve the species' likelihood of survival—for example, it might not assist food production or might improve weapon functionality and lead to extinction—nevertheless humanity's intellect has led it well so far, meaning it should be possible for humans to discover this unifying theory.

The theories we have so far work for the wide majority of cases. As such, searching for the ultimate theory becomes hard to justify. Then again, people argued this about relativity and quantum mechanics, which eventually gave us nuclear power and microelectronics. Thus, the search for a theory of everything might not help us survive, or ever change our lives all that much, but it does tackle questions we have asked for millennia. People want to understand the world and its order, where we came from and why we're here. This deep longing is the justification for this mission, a mission that asks for a complete description of the world we live in.

Hawking justifies his quest, perhaps his calling, to uncover a unified theory of everything, not on the basis of the technology it might create (though that is a possibility too), but instead on the fact that humanity has an innate desire to understand the universe and our role within in. Therefore, finding such a one-stop rule that unlocks the deeper truths of existence pays direct service to the inner longing that has gripped humanity since its earliest days

CHAPTER 2

What we understand today about forces and motion dates back to Galileo and Newton. Before them, people believed Aristotle, who said an object was naturally at rest and only moved if a force was acting on it. According to that logic, a heavier object ought to fall more quickly to the earth when dropped.

Aristotle once again offers an example of how not to suggest new scientific laws. Of course, it's easier to see he was wrong in hindsight, as Hawking notes that everyone was happy to accept Aristotle's teaching, without enquiring any further themselves.

Aristotle's teaching also said we could understand the whole universe just by applying logic, so no experiments were required. Galileo was the first to bother to check out the theory about weights falling at different rates. The story goes that Galileo tried it out by dropping things from the Tower of Pisa, but actually he rolled balls of different weights down a hill and measured their acceleration.

Galileo was the first to properly challenge Aristotle's teachings about object's natural state of rest, and actually checked it out for himself. In this way, Hawking shows the importance of an inquisitive mindset, as well as the necessity of double checking and observation.

Galileo found that each ball increased its speed at the same rate, regardless of its weight. The acceleration of the balls was directly proportionate to the incline of the hill, not their different weights. If one dropped a lead ball and a feather, the ball would drop faster only because air resistance slows the feather. Removing air resistance as a factor would see both fall at the same rate, as shown by astronaut David R. Scott, who performed exactly that experiment on the moon, where there is no air.

By setting up an experiment to check Aristotle's claim, Galileo showed that people had been wrong for centuries, simply because no one had checked. His finding changed how people viewed objects' movement and how forces worked on them. Later, when humans had advanced enough to travel to the moon, they performed further experiments to confirm his findings. Experiments, Hawking shows, gain better results than guessing.

Newton used Galileo's measurements as the foundation for his laws of motion. He deduced that the force (the balls' own weight) was constant, and this force caused the object to accelerate, not just set it moving. This meant the absence of force would leave an object moving straight ahead at a constant speed.

Just as Galileo had built on, and challenged Aristotle's earlier claims, Newton built on Galileo's findings, digging deeper into the science of acceleration. This not only confirmed Galileo's claims, but also revealed new findings.

Newton was the first to put this idea forward, in 1687. It is now called Newton's First Law, which states an object's speed will change proportionally to the force that affects it. The object's deceleration or acceleration is also affected by its own mass—the same force will be twice as strong if the object is half as big, and vice versa. For example, think of a car. A more powerful engine will produce higher acceleration, unless the car itself is heavier.

Newton's findings are foundational to people's understanding of the movement of objects to this day. The fact that the effects of these forces are proportional to the object affected means that people can predict and therefore control such movement. The idea seems simple now, but it took several round of further curiosity to unveil this fundamental law.

Newton also discovered the law of gravity, which is the idea that every object attracts every other object proportionally to its mass; the bigger the object, the stronger its gravitational attraction. The gravitational force between two objects doubles if just one object's mass doubles. If the other object were to triple its original mass, the overall gravitational pull of the two objects combined would be six times stronger than before. This is why all objects fall (or accelerate) at the same rate; if one ball has twice the weight of another, that effect is canceled out by the fact is also has twice the mass to move.

Just like his laws of motion, Newton's law of gravity states that the force acts on a object proportionally to that object's mass. This makes it a fairly simple rule to work with, something that suits Hawking's definition of a useful scientific theory. Objects therefore fall to the earth at the same rate no matter their weight. Bigger balls will experience a higher gravitational force, but that force has to pull on a bigger object.

This law of gravity also states that the force is proportionally smaller the further away the objects are from each other. A star's pull is one-fourth of that of a similar star at half the distance. Applying this law helps us to accurately predict the orbits of the planets and moons. If force were not proportional, and did not increase or decrease more rapidly as objects approached or drew away from each other, the planets would either spiral into the sun or escape its pull altogether.

Distance is also a factor in gravity, but again, as the force acting on objects is proportional to their distance from each other, the model is fairly simple for scientists to work with. This also agrees with observation, as the planets remain in fairly stable orbits around the sun, instead of careering off in another direction when a slight disturbance interferes with the balance, such as a passing meteor.

The main difference between Aristotle's approach and that of Galileo and Newton is the former's idea of the preferred state of rest, meaning an object would remain still if no force were acting on it. But Newton's laws of motion tell us there is no one standard of rest. For example, if we ignore the fact the earth is orbiting the sun, we could say a train is traveling over a still earth at 90 miles an hour. But you could also equally say the earth is moving south at the same rate, if you say the train is at rest. If you carried out Galileo's moving objects experiments on the train, Newton's laws would still apply—for example if you played table tennis on the moving train. Really, you can't deduce which object, of the train or the earth, is moving at 90 miles an hour and which is at rest.

Because, for example, a table seems to be perfectly still when you look at it, Aristotle never thought otherwise. But Galileo and Newton tested the theory out by analyzing the basics of how forces apply to objects. Newton's discoveries led to the next logical step, that you would have to find a perfectly static object to compare that table to. A seemingly obvious answer might be the earth, but the earth is hurtling through space around the sun, taking the table along with it. Objects, then, are never truly at rest.

Because there is no state of absolute rest, it is hard to determine if two events that took place at different times took place in the same location. If a table tennis ball bounces twice on a table on a moving train, someone inside the train will say the ball moved a few feet, but someone beside the track will think the bounces took place 40 meters apart as the train continued to travel along between bounces.

The next step, then, involves relating two, or more, moving objects to each other. If neither object is truly at rest, then the question is which point of observation one should take. Hawking provides an accessible, everyday example to show this is not a cosmic quandary only, but that ordinary situations involve the same issues. This is a fundamental question of how to perceive and explain the world.

This means we cannot give an event an exact location in space, contrary to Aristotle's teachings. The two people on the train would not be able to agree on the positions and distances of the event, and there is no reason to side with either one's version of events over the other's.

Each observer will have their own measurement of how the objects moved in relation to one another according to their own position and movements, and there is no reason to prefer one over the other because each viewpoint is valid.

This idea worried Newton, as a lack of absolute space didn't agree with his idea of an absolute God. He refused to accept the idea, even though his own laws implied it. Bishop Berkeley was one among many who criticized him for this, as he believed anything material, such as time, matter and space, were all illusions. Dr. Samuel Johnson in turn disagreed with the Bishop, and kicked a rock to show his dissatisfaction with such ideas.

Again, the reader sees the mighty fall victim to their own assumptions. In this case, Newton's religious beliefs create an inner crisis for the scientist, as his own discoveries challenge his worldview. Interestingly, Hawking chooses a religious thinker as an example of an exasperated onlooker, showing there is not necessarily a religion vs. science divide, only stubborn people and their own demons.

Aristotle and Newton both believed in absolute time, meaning the interval of time between two events could be definitely measured. This meant time was separate from space, which seems commonsense. These ideas have since changed, although the commonsense approach still works when dealing with everyday object like apples or slower-moving things like planets. When looking at things that move near or at the speed of light, however, this commonsense approach doesn't work at all.

Commonsense is not necessarily the most accurate of measurements. Here, Hawking does not blame Aristotle and Newton for their out of date ideas, as not everyone can discover everything all in one go, and he doesn't suggest they obstructed any discoveries related to the function of time. Instead, Hawking explains that in daily life, time moves at much the same rate for everyone, so time would seem absolute to the casual observer. But when it comes to much faster events, objects, or forces, the everyday approach cannot be trusted.

Ole Christensen Roemer, a Danish astronomer, was the first to notice that light had a finite, albeit very fast, speed, in 1676. He noticed that Jupiter's moons didn't seem to appear from behind Jupiter at a constant rate. He noticed the eclipses of the moons were later the further the earth was from Jupiter, and deduced it must be because the light takes longer to travel to the earth. His measurements were not very accurate, but it was still a remarkable achievement, especially as it came 11 years ahead of Newton's *Principia Mathematica*.

Roemer's curiosity led him to inquire further into the irregular orbits of Jupiter's moons. Instead of simply accepting what he saw, Roemer set out to understand why *the moons appeared from behind the planet at different times. His curiosity led to the discovery that light has a fixed speed. He even had a try at calculating that speed, although given his work came before Newton's crucial laws of motion and gravity, he wasn't very close.*

James Clerk Maxwell provided a full theory of the transmission of light in 1865, when he unified the theories that has been used to understand electricity and magnetism. He said wavelike disturbances in the electromagnetic field would travel at constant speeds, just like ripples in ponds. The different wavelengths (the distance between each wave crest) were different types of light; there are, for example, meter-long radio waves, centimeter-long microwaves, and smaller infrared, ultraviolet, X-rays, and gamma rays.

Further work on the nature of light uncovered its numerous varieties, as defined by its wavelength. This refers to the distance between each wave crest, or peak, and the next. Hawking makes a point of noting that Maxwell's discovery came from unifying the theories of electricity and magnetism. He hints at the wonders that might be uncovered at the unification of physics that he seeks.

This theory gave fixed speeds to different types of light, but Newton's theory had overridden the idea of absolute rest, so that raised the questions as to what the speed of light was relative to. People suggested the idea of an ether that occupied all space, which light traveled through. The light would travel relative to the ether, but would vary according to different observers.

Having discovered the different types of light, scientists were bursting with more questions about how this all worked. The new focus of their curiosity was how light moved. *It figures it must move through something. They proposed the idea of ether that gave a static position against which to measure light.*

For example, light should travel faster measured in the same direction of the earth's movement around the sun (i.e. toward the source of light), rather than at right angles (away from it). But Albert Michelson (the first American to win the **Nobel Prize** for physics) and Edward Morley tested this in 1887, and found it not to be true according to observation—the speed of light was the same.

Because the earth should be moving through the ether too, while light would travel at a fixed speed through the ether, it ought to appear to move at different speeds to observers at different angles to the earth's movement, for example moving toward the light source (the sun) as compared to at a right angle from it (looking away into space). But this was found not to be the case. More questions therefore arose.

Many people tried to explain this result. It wasn't until 1905, when previously unknown Swiss patent office clerk Albert Einstein suggested there was no need for the idea of ether if you accepted time was not absolute. Henri Poincaré, a French mathematician, made a similar point soon after.

With perhaps the hardest new idea to swallow so far, Albert Einstein earned his fame by suggesting time was not absolute, just as Newton had found centuries earlier that space was not absolute. By allowing different measures of time, the unfounded idea of an ether could be abandoned, as it had not agreed with observations.

This new idea was called the theory of relativity, which meant that the laws of science were the same for all freely moving observers. This brought together Newton's laws of motion and Maxwell's theories on light. No matter how fast they are moving, all observers will measure the same speed of light.

While the laws of science apply to all observers in the same way, and the speed of light is fixed, Einstein's theory of relativity stated that every observer will have a different measure of both space and time, relative to their own motion.

Although a simple idea, it had huge ramifications. Mass and energy were equivalent, as summarized in Einstein's famous equation E=mc2, and the theory that nothing is faster than the speed of light. This means that an object's motion-related energy will increase its mass, which will make it harder for the object to increase its speed.

Einstein's suggestion was a completely new way of looking at the universe. If mass and energy are equivalent, the faster an object moves the more its mass will be. This means objects need an exponential amount of energy to keep accelerating, as each step up in speed requires more energy than the last step to shift the object's ever-increasing mass.

This is more significant for objects moving close to light speed. As an object gets closer to light speed, its mass rises exponentially, taking ever-increasing energy to speed up. Objects cannot reach the speed of light, as it would take an infinite amount of energy to do so. Normal objects are thus stuck within the limits of relativity and cannot reach light speed. Only light, or other things with no mass, i.e. waves, can get to light speed.

Normal objects simply cannot gain enough energy to make the speed of light because the amount of energy needed is infinite. Thus, nothing can travel at the speed of light. But if the accelerating objects has no mass, and is a wave, it could be possible.

Relativity has changed the way we see space and time forever. Under Newton's theory, observers would agree on how long it took a beam of light to reach one place from another, but not the necessarily the distance between those points, because the idea of absolute space had been abandoned. If the time was constant, then the speed of light would have to differ between observers. But in relativity the observers must agree on the speed of light, so the time measured must differ. The time taken for light to travel equals the distance traveled (which the observers disagree on) divided by the speed of light (which the observers agree on). There is thus no absolute time. Observers all have their own measure, according to their own clock, and each observer's clock will not necessarily agree with others'.

In the theory of relativity, time and distance traveled are variable quantities, while the speed of light provides a stable measurement to use in calculations. This means each observer will have their own measurement of time and distance teveled, but must agree on the speed of light. Following in his forebears' footsteps, Einstein built on Newton's earlier work. His new approach answered questions that had plagued scientists for centuries, but it was not to be a final answer.

If the observers used radar to record the place and time of an event, they would send a pulse to that event that would then be reflected back. The time of the event is thus halfway between the pulse going out and returning. The distance is worked out by multiplying half the distance of the round trip by the speed of light. A space-time diagram, can be used by different observers moving at different speeds, and no measurement is more correct than any other, though they are all related. So, one observer could work out the time and position another observer would calculate if only the former knew the latter's relative velocity.

Einstein's ideas did not stay simply that—ideas. His discovery has been applied into real-life, everyday situations to make measurements more accurate. Here, the key to accuracy is understanding the differene perspectives of all related observers, each with a different and equally valid viewpoint. This allows each observer to know the different measurements another observer would have, an obvious advantage.

Today, this method accurately measures distances, because we can measure time more accurately than length. A meter is defined as the distance light travels in a tiny fraction of a second. (The historical definition is a platinum bar that is kept in Paris.) We can also therefore use an accurate measurement called a light-second—the distance light travels in a second.

Being able to apply Einstein's findings into real life situations leads to greater accuracy than previously available—a strong vote in favor of the advancements of science. Hawking provides the historical platinum bar as a static, inflexible contrast to Einstein's more dynamic solution.

Under the theory of relativity, distance is determined by time and light speed, so every observer must agree on the speed of light. There is no need for a theory of ether, which we cannot detect anyway. We must also accept that time is not independent of space, but rather combined in an idea called space-time.

Out with ether and in with space-time—Einstein's theory of relativity asked the scientific community for a total overhaul in approaching seemingly simple ideas like distances and time, yet Hawking does not hint that there was any reluctance to accept this. Perhaps Einstein's finding was so accurate it withstood any challenges, or perhaps the time was ripe for increasingly rapid scientific discovery.

In everyday life we can locate a position according to three dimensions of space, or coordinates. For example, a point in a room is measured by its distance from two walls and the floor or ceiling; a point on the earth is defined by a specific longitude and latitude, as well as height above sea level. We can use any three suitable coordinates. But we could not use miles north and west from Piccadilly Circus and height above sea level to locate the moon. We could pick points from among the sun or planets, but these in turn could not locate our sun compared to the rest of the galaxy. Thus, the whole universe is a group of such overlapping layers of relevant reference points.

Human curiosity drives the desire to know where something is, specifically. Describing a location, however, is not always a simple task—the location is relative to other nearby locations, as not every point of reference will be directly applicable. Hawking's example show that humans require specifics. Knowing the moon moves around the earth is not enough; humans have calculated just how far its orbits sits, etc.

An event happens at a certain point in space and time and can be measured according to four coordinates: three in space, and the fourth in time. These can all be arbitrary. In space-time, there is no distinction between space and time coordinates, like there's no difference between space coordinates, if they are suitable. These place the event in four-dimensional space-time.

As everything is always moving, an event describes what happens at a location in three-dimensional space with the added dimension of time. The moon was a certain number of miles from the sun two minutes ago, but it is no longer in the same exact place. Space-time is therefore four-dimensional.

Drawing diagrams of two-dimensional space is easy, like maps of the surface of the earth, because any point can be determined by latitude and longitude. Space-time diagrams can show time increasing on one axis, and one dimension of space on the other, with the other space dimensions ignored or shown via perspective that implies a third dimension.

Humans are not content to merely observe. They plot, measure, determine, and so on. With the creation of the idea of space-time came the creation of space-time diagrams, to accurately plot, measure, and determine events in four dimensions.

Hawking presents a figure showing time in years on the upward axis and distance in miles on the horizontal axis, as measured between the earth's sun and Alpha Centauri, a nearby star. The path of each of the two stars is a vertical line, and the diagonal line that connects them is a ray of light, which takes four years to travel the distance between them.

Humans have calculated that it takes light takes four years to travel to the earth's sun from a nearby star called Alpha Centauri. The graph Hawking uses to depict this fact takes into account the four dimensions required by space-time.

Maxwell predicted the speed of light would be constant whatever the light's source, which has since been proven true. As light is emitted, it spreads out like a sphere from a certain point similar to ripples that spread out from where a stone is thrown into a lake. Stacking up pictures of these ripples as they spread creates a cone, with the tip being the place and time the stone hit the surface of the lake. Light spreading from a source forms a similar cone, called the event's future light cone. We can also create a past light cone, which is the group of events that light can reach from a given event (Fig 2.4).

Hawking describes a handy graph depicted on a two-dimensional sheet or screen but implying three dimensions with perspective (i.e. imagining the depth into the paper or screen). Scientists use such graphs to plot other events in relation to an original event at the tip of the cone, allowing for greater analysis in four dimensions.

Given an event, as represented on the graph as P, all other events can be classified into one of three groups. Events that can be reached from event P by anything at or slower than the speed of light is the future of P. Only these events will be effected by P. Events in P's past are those from which P can be reached at or under the speed of light. The elsewhere of P is everything else. These events are not affected by nor affect P.

The events analysed in relation to the original event, P, can then be classified, as the observer seeks ever greater specificity. Unsatisfied with analyzing events in isolation, people have devised these graphs to allow closer cross-analysis.

For example, if the sun went out at this very moment it would not affect events on earth right now, as it takes 8 minutes for the sun's light to reach us. After those 8 minutes, the earth would be in the future light cone of the event of the sun going out. In the same way, we do not know what is happening right now in distant space. We are seeing the universe as it was in the distant past, on the far end of past events' future light cones.

Just knowing the sun's light reaches the earth was not enough. Scientists have precisely measured the time it takes for the light from the sun to reach earth. The next step is to realize that observers from the earth are always seeing the sun in its past, and the step beyond that, that the same view of the wider universe is even more outdated.

Ignoring gravitational effects, like Einstein and Poincaré did back in 1905, the resulting theory is called the special theory of relativity. All light cones would be identical and point in the same direction as light speed is the same at every event and in every direction. Any object's path is therefore represented as a line in every relevant light cone. This approach was successful at explaining why the speed of light seems the same to everyone, and what happens when traveling near the speed of light.

Despite the fact that nothing, including people, can travel at the speed of light (as Hawking explained earlier), scientists were still determined to devise a way to map out such movement. In such models, light speed becomes a fixed number, allowing greater analysis of fast-moving obejcts.

But this theory is inconsistent with Newton's laws on gravity, in which distance is a factor, meaning moving an object would affect the force applied to it instantly. This implies gravitational effects take effect instantly, which doesn't work with the special theory of relativity's idea that nothing moves at or above the speed of light.

Einstein's theory had caught a snag. Gravitational forces could theoretically move faster than the speed of light, which didn't fit with his model. Einstein could have taken the same route as Ptolemy, when the latter ignored the fact the moon should have appeared twice as big sometimes if it followed the route his model suggested.

In 1915, Einstein put forward the idea of the general theory of relativity. He suggested that gravity is not like other forces. Rather, it is the result of the fact space-time is not flat. It is curved according to the mass and energy distributed across it. The earth is not forced to move in a curved orbit by gravity. Instead, it takes what is closest to a straight path in curved space. This is called a geodesic, the shortest path between two points. A geodesic of the earth is called a great circle, and is used by airline navigators to determine the shortest distance between two airports.

Einstein went back to the drawing board, and came up with a new and improved theory that better fit observations. By accepting the limitations of his previous theory, Einstein made yet another landmark suggestion that changed the way people see the universe, again. Time is not absolute, and space is not flat.

In general relativity, objects take a straight route in curved, four-dimensional space-time, but seem to take curved routes in three-dimensional space. For example, an airplane flying straight will have a shadow that seems to take a curved path on the two-dimensional ground.

Einstein's discovery had real-life applications in that it helps to understand how planes navigate around the globe and how large bodies pick out routes in the cosmos. His concept turned previous perceptions on their head, to offer a different perspective never before considered.

The sun's mass and resultant gravitational force curves space-time so that although the earth travels straight in four-dimensional space-time, it looks like it follows a circular orbit in three-dimensional space. Newton's law of gravity predicted the planets' movements fairly accurately. But the gravitational effects are so strong on Mercury, which is closest to the sun, its orbit looks very elongated. This extra-long axis causes Mercury's orbit to rotate by one degree every ten thousand years. This fact was accounted for in the new theory, and helped to confirm Einstein's new proposition. Even smaller deviations have been found elsewhere and confirmed the theory's predictions since.

Einstein's new theory built on his earlier theory that had built on Newton's earlier theory, and so on. Einstein's idea could predict the planets' movements more accurately because he started from and expanded on his predecessors' work. In this way, Hawking describes the ever-advancing progress that can be achieved by continuing to challenge and expand on the theories currently used. Hawking shows that, so far, there have always been more layers of knowledge to dig into, and humans' curiosity has never exhausted.

Light also seems to not take straight paths through three-dimensional space. Light should also be bent by gravity, according to general relativity. Light cones near the sun ought to bend slightly inward, because of the sun's mass. Light from a distant star that passes by the sun ought to bend, making the star appear to be where it's not. If the light from the star always passed near the sun, we would not be able to tell. But the stars move relative to each other as the earth orbits the sun, so different stars pass behind the sun from our perspective.

The next question in the long line of science's ongoing inquiries into the workings of the universe was how Einstein's new version of his relativity theory would affect light's movement through the cosmos. The phenomenon of the sun bending light might not affect day-to-day life on earth, as most things people need to see to survive are a lot closer than that. Still, scientists theorized that light ought to bend around the earth if the theory of general relativity was right, and set out to check.

It is hard to see this effect of light bending around the sun because of the latter's gravity, because the sun's light is brighter than that from more distant stars. But it is possible to observe the effect during a solar eclipse, because the sun's light is blocked, allowing the bent light from the distant star to be measured. This effect has since been observed and measured, confirming the theory.

Undeterred by the difficulties of measuring this effect, scientists waited until the opportune moment, during an eclipse, to see if their guess was right. Their suggestion was found to match with observation, fulfuilling Hawking's requirements to be considered a solid theory.

According to general relativity, time should also run more slowly when closer to objects with large mass, like the earth. The higher light's energy, the higher its frequency (or waves per second). Light loses energy to escape the earth's gravitational field, making its the frequency slow and in turn making it look to an observer above the earth like everything below is happening more slowly than where the observer is. This idea was tested in 1962 with a pair of very accurate clocks on the top and base of a water tower. The clock at the base ran more slowly than that at the top, as predicted. This has great significance on navigation systems for satellites.

Although it might not have seemed directly useful initially, the discovery that light bends according to gravitational effects has indeed had real-life applications. By extension of the theory, light should lose energy as it tries to escape the earth's gravitational pull, causing time to slow. Now that humans have put satellites into orbit, such differences in time are critical to ensuring their safe operation. Hawking provides this example to show that greater scientific understanding does improve humanity's ability to survive—as satellites acting erratically and crashing to earth would pose a very real risk.

Newton's laws ended the idea of absolute space and relativity ended the idea of absolute time. If twins separated, with one living on top of a mountain and one living by the sea, the first would age more quickly, and would be older when they met again. In this example the difference is small, but if one twin took a ride in a spaceship at the speed of light, he would be much younger than his brother by the time he returned to earth. This is known as the twin paradox. Really, there is no absolute time, instead each person has their own measure of time.

Hawking now provides a more human example to emphasize the previous point and bring to life the reality and consequences of the theory of relativity. The more humanity advances, the greater the effects such concepts will have on daily life. It will no longer be satellites alone that have a totally different measure of time, but even family members.

Space and time were considered fixed and separate arenas before 1915, unaffected by what took place within them. People thought they both went on forever. But with general relativity that thinking has changed considerably. Space and time are affected by objects' movement and forces, and space-time in turn affects the movement of those forces and objects. Just as space and time affect everything in the universe, there is no meaning to space and time outside the universe.

Einstein's theories asked for a considerable change of perspective among the scientific community. Throughout his explanation of the theory of relativity, Hawking does not comment on any opposition to it. It could be that no challenges to the theory are worth the space they would take up in this book. It could also be that Hawking intends to impress the significance of Einstein's revolutionary model. Either way, Hawking shows that scientific progress will continue apace, as knowledge supports and spurs on ever more knowledge.

The world was now dynamic, rather than unchanging, was expanding, and possibly finite, with a beginning and an end. This was the start for Stephen Hawking's own work in theoretical physics, and later he showed with Roger Penrose that Einstein's general theory of relativity suggested there was indeed a beginning and end to the universe.

To wrap up the chapter, Hawking hints toward the next pages in the history of scientific progress to be discussed in the book. The lineage continues.

CHAPTER 3

On a moonless night the brightest objects are most likely Venus, Mars, Jupiter, and Saturn. There are also many stars, similar to our sun, just farther away. But they are not fixed; they all move relative to each other, which we can see because these stars are relatively close to us. As the earth moves round the sun we these stars move against the background of more distant stars; the nearer the stars, the more they seem to move.

Ever since the earliest civilizations, humanity has wondered at the stars. Hawking opens this chapter by summarizing a model of the universe that might seem obvious to modern-day readers, but would have astounded readers in Aristotle or Ptolemy's day. Essentially, Hawking reminds the reader how far humanity has come that such knowledge is now commonplace.

Proxima Centauri is the nearest star and is four light-years, or 23 million million miles, away. Other visible stars are mostly within a few hundred light-years, while the sun is just eight light minutes away. These stars are concentrated in a band we call the Milky Way. Even in 1750, astronomers thought this must be because we are in a spiral galaxy. Sir William Herschel confirmed this some decades later, but the idea only gained traction in the 1900s.

Providing more details, Hawking begins to add scale to the model, with some astounding numbers. Modern scientists' understanding of the universe far outranks that of the classical thinkers, and the addition of dates helps the reader to piece together the history of the modern model of the universe.

In 1924, Hubble defined our modern understanding of the universe when he showed that ours was not the only galaxy, proving there were many others, with lots of space in between. To measure how far away they were, he measured their luminosity, which is affected by their distance from us.

Astronomer Edwin Hubble, after discerning that there were other galaxies, did not stop there. He set out to measure their distances, and used ingenious methods to do so.

Hubble worked out distances to nine galaxies this way, showing how there are hundreds of thousands of millions of them. Our galaxy is 100,000 light-years wide and rotating. Our sun is an average star among one of the galaxy's spiral arms. We've come a long way from thinking we were the center of the universe.

Hubble's findings were humbling for the human race, yet, it seems, widely accepted. Having built up to this moment from the opening lines of the chapter, Hawking notes just how far humanity has come from thinking the universe revolves around us.

Newton discovered that by using a prism we can measure the different colors of the light spectrum. By using a telescope and a prism, we can see the light make up of whatever star or galaxy focused on. We can in turn tell a light's temperature from its spectrum. Missing colors indicate what chemicals are in each star.

Scientist have devised resourceful ways to determine the make up and temperature of far distant stars. Those who studied the chemical components of stars in other solar systems may well have never known how their work would have contributed to humanity. Perhaps they were simply curious.

When in the 1920s scientists looked at stars in other galaxies, they had the same missing colors as similar, closer stars, but they were all shifted toward the red end of the light spectrum. The Doppler effect tells us that as something moves away from us, each wavelength will be longer, while if it is approaching us each wave would reach us more quickly. As light is a wave, its wavelength will lengthen as an object moves away from us, and our eyes see longer wavelengths as red light.

By understanding the properties of light, scientists studying distant stars could tell that they were moving away from us, just from the spectrum of the color of light that filtered through the prism set to the telescope. Studying these patterns of light that reached them on earth showed the scientists the movements of the wider cosmos.

As Hubble catalogued the galaxies and their distances from us, he found most galaxies were red-shifted, meaning they were moving away from the earth. Indeed, the red shift is proportional to the galaxies' distance from the earth, meaning the further it is the faster it is moving away. As such, the universe must be expanding.

This analysis lead to the next great revolutionary scientific upset: the universe is expanding in all directions. This discovery did not happen in isolation, but was based on the layers of prior discoveries that supported the work. Hawking's point, therefore, is that the results of previous curiosity will both spur and support future curiosity.

This was such a great intellectual revolution that people wondered how it had not been thought of before. Newton should have guessed it, as otherwise the universe would have contracted under the influence of gravity. But as the universe is expanding, this cancels out that gravitational pull. If the universe is expanding beyond what gravity can balance, it could expand forever, like a rocket bursting out of the atmosphere and continuing through space instead of falling back to earth.

While Hawking shows that many new ideas have met with incredulity or even aggression, Hubble's discovery was so obvious it was almost embarrassing that it hadn't been suggested before. This new discovery, as with all the ones preceding it, gave rise to more questions, such as whether the universe will always be expanding.

People could have realized the universe was expanding from Newton's theory of gravity, but everyone at the time seemed set on believing in a static universe. Even Einstein overlooked this idea in his general theory of relativity. Instead he thought up a kind of anti-gravitational force he called the cosmological constant.

Hubble's discovery was based on fundamental laws known since Newton's day, and the latter himself should have made the next logical jump, although he was too preoccupied with disliking the idea of nonabsolute space. Einstein had missed the idea too, as he was so certain the universe was static.

Yet a Russian physicist called Alexander Friedmann tackled this head on. He assumed first that the universe looked uniformly the same in every direction on the large scale, and second that this would be true from wherever you looked in the universe. This alone suggested the universe is not static, and he suggested it before Hubble's landmark discovery.

Before Hubble's announcement, however, Friedmann had made the same suggestion. The difference, it seems, was that he suggested it, but could not show it in the same way Hubble did.

In nearby space, the universe does not look uniform, but further out it does. This was further backed up by two American physicists, Arno Penzias and Robert Wilson. They tested a very sensitive microwave detector, which picked up a lot more background noise than expected. After checking their equipment, then taking measurements in all directions as the earth traveled around the sun, they determined it was coming, uniformly, from the whole universe. They had confirmed Friedmann's first assumption.

Penzias and Wilson, albeit unwittingly, provided the observational evidence that Friedmann's theories required. Although the two Americans at first thought their equipment was faulty, their curiosity got the better of them, and they were determined to discover where all the noise their detector was picking up was coming from. It turned out, it was from the entire universe.

At the same time, two other American physicists, Bob Dicke and Jim Peebles, were setting themselves up to look into microwave radiation to examine George Gamow's idea the early universe was hot and glowed brightly. They said it was so long ago that energy would now have red-shifted to become microwave radiation. Penzias and Wilson heard about this, and saw they had already found the evidence. The latter won the **Nobel Prize** in 1978 for their work, which seems hard on those who suggested the theories in the first place.

Along with confirming Friedmann's work, Penzias and Wilson also provided proof for numerous other scientific theories, simply because they pulled at a loose string. Hawking seems ambivalent about whether Penzias and Wilson ought to have won the Nobel Prize for their work over the other scientists, emphasizing the importance of asking questions and making suggestions, even if one cannot prove news ideas immediately.

If the universe looks the same in every direction, it should look the same from any other point in the universe too. We argue this on the basis of modesty; we cannot prove it yet. In Friedmann's model, the universe is expanding, like a balloon with every point expanding from every other point. The further away two points are, the faster they'll be expanding, just as Hubble found. But despite his accuracy, Friedmann's work was not known in the West until Howard Robertson and Arthur Walker did similar work.

While philosophers used to argue that the earth was the center of all existence for mystical reasons, modern scientists seek to humble humanity in the interests of modesty, given the awesome scale of the universe they are studying. A little humility and open-mindedness seems to have brough humanity a long way.

Three models obey Friedmann's assumptions, though he only suggested one himself. In the first, gravity can slow and eventually stop the expansion. Finally, the universe will contract again. In the second, gravity can slow the expansion a little, but not halt it, until it steadies to a constant rate. In the third, the gravity is just below where it can stop the expansion, so the universe continues to expand forever, but at an increasingly slow rate.

After realizing the universe must be expanding, Friedmann's next question was just how fast that expansion was. If the universe was expanding too rapidly for gravity to balance it out, the universe might expand forever. If not, the universe would collapse back in on itself under its own gravity. Friedmann assumed the latter.

In the first model, or theory, the universe is finite, yet does not have a boundary. Gravity bends space around itself, so space is curved, like the surface of the earth. When combining the general theory of relativity with quantum mechanics (as discussed later), space and time can be finite without a boundary. But this doesn't mean you could travel right around the universe back to where you started; it would collapse again before you managed it. You'd have to travel faster than light, and you can't. In the second model, the universe is bent like a saddle, so it is infinite in space. In the third model, space is flat and infinite.

While the first model might hold promise for circumnavigating the universe, it is only the wishful thinking of adventurous humans. It would take a normal object traveling under the speed of light too long, and the universe's gravity would begin to draw everything back together, causing the universe to collapse in on itself. As Hawking explained, normal objects with mass require exponential energy to speed up, and infinite energy to reach the speed of light, so humans will most likely never circumnavigate the universe.

To know which model fits best, we need to know the universe's rate of expansion and average density, to determine if gravity will slow or stop the expansion. We know from the Doppler effect that galaxies are moving away from us at a rate of 5 to 10 percent every billion years. Our estimate for density is even more vague. What we can see and measure is less than one percent of the mass required to halt the expansion. Even what we cannot see but think is there would not add up to enough. Right now, it seems the universe will expand forever, but even if it did recollapse, it would most likely be billions of years after humans had died out anyway.

Although the ultimate fate of the universe, if it were to collapse, would not have any bearing on the human race as the species would most likely have died out anyway, scientists still pursued the question of which of these models is right. The attempt to choose any Friedmann model with certainty only highlights just how much humans still do not know about the universe, including what humans don't know that they don't know.

All the Friedmann models start out with a beginning where the space between everything was zero—the universe was infinitely dense and curved. Laws of science break down at this point. This big bang singularity means any previous events would not have any meaning to us now. In a sense, then, time began with the big bang.

As St. Augustine pointed out, time is a property of this universe and has no meaning outside of it. If the laws of science break down at the big bang, any events previous to that can be considered beyond the boundaries of this universe, with no effect on events taking place today. As such, the best option is to focus on what is discoverable and say time started with the big bang. There do have to be limits to human curiosity it seems, with the boundary being our own universe—as this is all humans can observe, measure,e and therefore truly know.

While the church liked the big bang model because it leaves room for God, many dislike the idea. Hermann Bondi, Thomas Gold, and Fred Hoyle proposed the steady state theory, where matter spontaneously comes into being in the gaps between expanding galaxies. A group of astronomers headed up by Martin Ryle looked into radio waves from different galaxies, and found variations that disproved the theory. Penzias and Wilson's earlier discovery also suggested the universe had been denser in the past, further disproving the theory.

Somewhat ironically given earlier examples Hawking uses, the church grasped at the big bang theory to support its own teachings, while scientists disliked the idea because it backed religious ideas. Hawking's ironic tone dealing with both approaches shows his frustrations with those who cannot view new ideas objectively. Neither approach helps to ensure the continued progress in humans' understanding of the universe.

Russian scientists Evgenii Lifshitz and Isaac Khalatnikov also tried to disprove the big bang. They said that as galaxies do not move directly away from each other, perhaps they were simply nearby at the beginning, not in a singularity. They created many more models, and found that there were examples for both sides, retracting an earlier statement that said there were many more scenarios in which there was no big bang. They did show that a big bang was *possible* under the general theory of relativity.

With this example, Hawking shows there can be redemption for those who approach scientific undertakings with a biased agenda. While Lifshitz and Khalatnikov set out to disprove the big bang theory, rather than simply assess its validity, they ended up demonstrating that the big bang was a legimate theory within the realms of possibility, humbly eating their hats in the process.

In 1965, Roger Penrose showed that stars can collapse in on themselves to become singularities, in this case, black holes. While Penrose only talked about stars, a young Stephen Hawking saw the relevance this had for the big bang theory. After surviving longer than expected after being diagnosed with Lou Gehrig's disease, Hawking took the research matter up for his PhD. He suggested that if the universe is infinite and expanding too fast to recollapse, it should have started at a singularity. Penrose and Hawking's resulting paper in 1970 faced opposition. But the math held out, and now everyone tends to assume there was a big bang. However, Hawking himself has since changed his mind, when taking quantum mechanics into account.

Stephen Hawking now enters the book as a character in his own right, in addition to being the narrative voice. He set out to prove that infinite Friedmann models necessitate a big bang singularity, but faced opposition from those who simply did not like the idea. Hawking's derision for those who challenged his work does not arise from his bias toward his own work. In fact, he later changed his mind about the idea based on subsequent discoveries! Instead, Hawking criticizes his critics' prejudice and lack of objective judgment.

Over the millennia, our understanding has changed significantly. Penrose and Hawking's work showed that Einstein's general theory of relativity is only a partial theory. It breaks down at the beginning of the universe. When the universe was squeezed into infinite density, quantum mechanics comes into play. As such, their focus turned from the massive to the miniscule.

If Einstein's general theory of relativity cannot describe what happens in singularities, and explains the phenomena only as the break down of scientific laws, then it follows that the laws themselves are not good enough, yet. General relativity, while crucial in solving some problems, cannot aid scientists to uncover the hidden truths in singularities such as black holes or the big bang. Time, then to move the discussion onto a new topic.

CHAPTER 4

In the early 1800s, Marquis de Laplace thought that because science was doing such a good job explaining everything, that it would be possible to predict everything if only scientists knew the total make up of the universe at one moment in time. He thought this could extend even to predicting human behavior. This idea remained influential for decades, though it was unpopular among those who believed God's freedom to act should be uninhibited.

Laplace was optimistic about a unified theory of everything more than a century ahead of Hawking. But he faced opposition from religious groups, who disliked how this idea affected their notion of an omnipotent god. This opposition seems to have been ineffective, as Hawking states the idea remained popular, showing the enthusiasm spread. People wanted to know exactly how the world worked, and couldn't be put off the idea, once offered.

Later, Lord Rayleigh and Sir James Jeans suggested hot bodies, like stars, radiate energy at infinite rates; this would mean the total energy emitted would be infinite, however, which is not considered possible. Max Planck then suggested that light, and all waves, would be emitted in certain amounts, called quanta. Higher frequencies of light would be emitted in higher-energy quanta. This would make the energy released, and the energy the star lost, finite.

Work continued on unfinished business in the scientific arena. Planck's discovery of quantum theory did a lot to help scientists understand how stars and other objects emit energy, as well as how to apply that energy in the lab. Slowly, scientists were eliminating infinities from humanity's understanding of the universe.

Werner Heisenberg used this theory to create his uncertainty principle. To measure a particle's position and velocity, one must shine light on it to see where it is. The higher the frequency of the light in the quantum, the more accurately you can see the particle, because the wavelengths of the light will be shorter. But that means more energy will be applied to the particle, therefore changing its position or velocity. So, the more accurately one wishes to measure a particle's position or velocity, the more uncertainty created. This is a fundamental principle of the world.

Scientists can see particles by shining light with high-frequency wavelengths on the particles, because if the particle is smaller than the gap between each wave crest, it cannot be directly detected. As Planck's quantum theory of light tells us, high-frequency quanta (or packets) of light have more energy. That means the more accurately one wants to see the particle, the more energy that is then applied to that particle, and the more that energy will push the particle off its original course. Essentially, scientists cannot definitively position particles in space-time.

This was the end of Laplace's idea of determinism. There was still place for God in this model, but it did not help mere mortals to understand how he might work. Instead, it was better to leave out of the theory that which humans cannot see.

If scientists cannot accurately locate particles, there is no way they can definitively know the make up of the entire universe, meaning Laplace's hopes of being able to predict even human behavior were dead. But, this uncertainty left lots of room for God's autonomy, which Hawking notes to show how religion tends to occupy the unknown or unknowable aspects of the universe.

Heisenberg, Erwin Schrodinger, and Paul Dirac in the 1920s created quantum mechanics based on the uncertainty principle. This theory does not predict definite outcomes, but potential outcomes. It works on the basis of probability, with no definite outcome for each individual observation, therefore introducing randomness into science. Einstein objected to this approach despite the fact his **Nobel Prize** was partly awarded for his contributions to the theory. He said, "God doesn't play dice." Yet quantum mechanics works very well with observations and it underlies all of modern science, including electronic chips. The only areas of science that not yet been integrated into this theory are gravity and the larger structure of the universe.

Science, once again, was turned on its head. Scientists could no longer confidently place particles in space-time, let alone accurately predict their movements. This was something Einstein could not accept, it seems on religious grounds based on the quote Hawking provides. Nevertheless, science works on objective assessment of observations, Hawking emphasizes, in continuing to discuss the theory that expanded and developed whether Einstein backed it or not.

Planck suggested that light, although a wave, could act as a particle, being emitted only in certain quanta. Heisenberg's uncertainty principle made particles seem more like waves, with their movement spread out according to probability. There is therefore a duality between waves and particles in this new theory. This means scientist must consider the interference of these waves, where the peak and a trough of two waves meet, canceling each other out. This same effect creates the colors in bubbles, as waves overlap and strengthen or cancel each other out.

Even the distinction between particles and waves became blurred in this new age of science, something that scientists seemed to absorb on the basis that it agreed with observations. This necessitated a new approach, again. Hawking provides an everyday example here to help the reader, who, like the scientists of the time, now must wrap their head around another new perspective.

If particles can be like waves, this canceling out happens with them also. If one passes light through two slits in a paper divide onto a wall behind, the light will generally travel different distances from the light source, and through the slits, to reach the wall. Therefore, the wavelengths of these beams of light will overlap rather than arrive "in phase with each other," canceling out where a wave's trough hits a peak, or strengthening each other where a peak combines with another peak. This creates a fringed pattern of light on the wall, as the light has not hit in a uniform manner. This happens with particles in the same way. But when passing just one particle through one slit at a time, the pattern still shows, as though it had passed through both slits at the same time and interfered with itself.

When a wave crest meets another wave crest, they combine into a larger crest. When crest meets a trough, they cancel each other out into nothing. So, as light waves bounce around on their way to the wall, they are not all traveling in unison with each other, creating lines of light on the wall that represent this interference that happens as different waves meet. The same effect happens with particles, as crests support crests and cancel out with troughs on their passage through the divide, toward the wall. The really remarkable thing is this happens when passing just one particle through the divide! The question therefore is how does the one particle cancel itself out, as it ought to only take one path, rather than interfere with other particles.

This has helped scientists to understand the atom. At first atoms were seen as mini solar systems, with a nucleus orbited by other miniscule particles, but many wondered why it did not all collapse. Niels Bohr suggested in 1913 that electrons could only orbit at specific distances, which would balance it all out. According to quantum mechanics, the electrons would move as waves, and therefore would only form orbits where the wavelengths were whole numbers. If the wavelengths needed to complete an orbit was not a whole number, then the wavelength would cancel itself out when the electron's trough met a peak on its way around.

Using the same logic, Bohr discerned that an electron's wavelength would eventually cancel itself out on its orbit around the nucleus of an atom if its wave crests didn't match up each time round. Otherwise, a crest would eventually meet a trough and cancel out. As such, electrons would fit into the orbits where their wavelengths would be consistent with each orbit, holding the atom's structure together.

Richard Feynman created the sum over histories theory to explain this. A particle is said to travel from A to B by every possible path. By adding up all the wavelengths for all the paths, and finding which cancel each other out, one can find the probability of traveling from A to B. This provides the math to predict particle movement, though in practice it is too difficult for calculating the movement of anything more than a simple atom.

Bohr's work allowed Feynman to take the next step and find a mathematical way to assess all of this unpredictability and find the most likely paths electrons would take even in molecules, which are a group of atoms. As Hawking notes, however, in reality the math is too hard to do, meaning scientists are left accepting the unpredictability of the universe's smallest particles.

Einstein's general theory of relativity is considered a classical theory because it does not include quantum mechanics. This does not lead to inconsistency, though, as gravitational forces are so weak compared to other forces. But gravity would be much stronger in black holes or at the big bang, and as such needs to be integrated into quantum mechanics. Just as the idea of atoms collapsing was wrong, so too might be ideas of singularities. Scientists need to unify these two theories and already know some properties such a theory would have, as well as the areas in which it would have the greatest significance.

As Hawking mentioned previously, the unification of physics depends on integrating the general theory of relativity and quantum mechanics, which might not be as mutually exclusive as they appear at first glance. He holds out hope because achieving unification would answer some of the most perplexing mysteries scientists have grappled with, mysteries they cannot even see and which, potentially, might be proven not to exist at all.

CHAPTER 5

Aristotle thought the universe was made up of earth and water, which tended to sink (gravity), and wind and fire, which tended to rise (levity). He thought matter was continuous, meaning matter could be divided and divided again infinitely. Fellow Greek philosopher Democritus disagreed and believed in atoms.

Hawking once again uses Aristotle to show, first, the errors of assuming without evidence, and second, how far the human race has come in understanding the universe, thanks to modern scientific approaches.

The argument wasn't settled until 1803, when John Dalton discovered the existence of molecules. Einstein provided important evidence when he explained the random movement of dust in liquid was caused by the dust and liquid atoms colliding. J. J. Thompson at Cambridge had already proven the existence of electrons, and later Ernest Rutherford showed the atom had a nucleus, around which the electrons orbit.

Scientists achieved rapid progress once they began to actually look for such particles rather than debate them, and also due to the assistance newer technologies provided. Each discovery supported and spurred on the next, in the ongoing chain that is scientific progress.

James Chadwick discovered the neutron (which has no charge) made up the nucleus of an atom along with the previously discovered proton, and later won the **Nobel Prize** for his discovery.

Chadwick's Nobel Prize demonstrates that people welcomed these discoveries, seeing their worth in the mission to understand the universe and its workings.

In the mid 1900s, Murray Gell-Mann discovered quarks and won the **Nobel Prize** for his work on them. There are six "flavors" of quark: up, down, strange, charmed, bottom, and top, which were found in succession. Each comes in three "colors": red, green, and blue. These names are just labels. Quarks form the proton, electron, and neutron. Scientists can create other particles from quarks, but these are unstable.

After finding the constituent parts of the atom, such as the proton and electron, and their functions, scientists soon set about determining what made up these particles, eventually finding quarks. Their curiosity still unquenched, scientists proceeded to determine the different kinds of quarks and how they relate and function.

The question remains as to what the truly indivisible particle is. The smallest wavelength of light we can see is larger than these particles, so we cannot "look" at them. But if particles are also waves, and higher-energy particles have smaller wavelengths, scientists can aim to harness ever-higher energies to look at ever-smaller particles. As technology advances, scientists might even be able to achieve higher energies, but scientist think they already have found the smallest particles in existence.

The obvious question is how long this process of discovering ever-smaller particles will continue. There is a current impediment, Hawking explains, in that scientists do not yet have the tools to look more closely, as the highest energy yet harnessed and applied in such experiments still cannot directly see the smallest particles thought to exist.

Particles have a property called spin, which reveals what a particle looks like from different directions. A particle with spin 0 is like a dot—it looks the same when viewed from any angle. Spin 1 means it is like an arrow—it must turn one time to look the same from the same viewpoint. Spin 2 means the particle can turn halfway and look the same, and so on. There is even a spin ½, which means a particle must turn twice before it looks the same. Particles of spin ½ are all the particles that take form as matter. Particles of spins 0, 1, and 2 create forces between matter particles.

Having found these infinitesimally small particles, scientists moved on to determining their nature and characteristics. Scientists devised a way to distinguish particles from one another that revolves around this idea of spin, referring to how many times a particle must rotate to still look the same.

Wolfgang Pauli won the **Nobel Prize** for discovering that two matter particles cannot exist in exactly the same space going at the same velocity. This is called the Pauli exclusion principle. The way particles inherently repel each other and spread out is what gives the universe its structure and stops it from collapsing and becoming "soup."

If spin ½ particles, which make up matter, are in the same place, they will not have the same velocity, meaning they will soon move away from each other. The fact that matter particles inherently repel each other in this way gives the universe structure, because if they didn't, there would be nothing to stop all matter from clumping up together, instead of forming into more comlex structures, something scientists have not taken for granted.

Paul Dirac was the first to propose a theory consistent with both the general theory of relativity and quantum mechanics. He showed mathematically how spin ½ works and predicted that electrons should have partners, antielectrons or positrons. This later lead to his **Nobel Prize**. Indeed, every particle has an anti-particle, it is now known, and the two can cancel each other out.

Spin ½ particles must turn twice before they look the same, a phenomenon Dirac explained mathematically. His prediction that there ought to be antielectrons was later proven correct, earning him a Nobel Prize, a further sign that, provided one has the evidence to back it up, the scientific community would welcome new and challenging ideas.

Forces acting between matter particles are carried by the force particles—that is, those particles of spin 0, 1, and 2. Matter particles emit the force-carrying particles, which then change the particle's course from the recoil resulting from the emission. The force-carrying particle is then absorbed by another matter particle, also effecting the velocity of this second matter particle. These force carrying particles do not obey the Pauli exclusion principle, so they can build up to become bigger forces. Their range depends on their mass, and they are considered virtual particles as they cannot be detected directly.

Just as a gun recoils from the effort of shooting a bullet, a particle will change its velocity when it emits a force-carrying particle. Another particle absorbs this energy, causing its velocity to also change. These force-carrying particles, however, cannot be detected directly. In this way, scientists have been able to study particles they cannot even see.

Still, scientists can see the effect such force particles have. They're observable in the form of "classical" waves, such as light or gravity. Scientists have created four classes of forces for these types of particles, which they hope one day to unite as four types of one single force.

Scientists have classified these force-carrying particles they cannot directly detect into four categories according to their effects, in their determination to understand everything.

The first class is gravity. Every particle feels gravity, according to its mass and energy. It is also the weakest of the four forces. It always attracts and acts over long distances, unlike other forces. Big things, like the earth, can create a large overall gravitational force. A particle of spin 2 called the graviton carries this force. Because it has no mass, the graviton can travel great distances. Although a virtual particle, gravitons are the reason the earth orbits the sun.

Gravity, the first of these unseen forces, is something humans come across in every moment of daily life. While this force is unseen, its effects are clear. The rationality of studying even unseen realities in the universe is therefore apparent.

Another class is the electromagnetic force. This affects only electrically-charged particles like electrons, but not gravitons. It is much stronger than gravity, and comes in the form of positive or negative charge. If two charges match, such as positive and positive, they repel each other, while opposite charges attract each other. On the small, atomic scale, electromagnetic forces dominate all activity. This force arises from the exchange of photons. Real photons are made when electrons move along the set orbits of an atom. We see photons as light, and they can be captured in photographs.

Hawking offers an everyday example of such particles when discussing photons, which are captured in photographs. Understanding these laws allows humans to create technologies that preserve precious memories and remember loved ones. Humanity's curiosity about the workings of the universe prompts ingenuity, which is applied with sentimentality, a feeling which the curiosity perhaps originates from in the first place.

The third force is the weak nuclear force. It creates radioactivity and acts on matter particles, but not force-carrying ones. Abdus Salam and Steven Weinberg both put forward ideas on this force that linked it with the electromagnetic force in 1967. They said three types of particle called massive vector bosons carried this weak nuclear force, and are spin-1 particles. These particles only seem different at low energies, and at high energies they all act the same, much like a roulette ball has 37 slots to fall into at low energies but flies round and round in a circle at high energies; at low energies, it looks like there are 37 types of ball. This is called spontaneous symmetry breaking, when at low energies these particles break their symmetry, take on higher masses, and travel shorter ranges.

Salam and Weinberg's theory suggests how forces might act when they have higher energies than humans are currently able to produce. As such, it is currently unprovable. The idea is that the different types of forces are all ultimately the same, which can be seen when they have high energies. But when viewed at low energies, as they are today, they are stuck with one function due to their lack of energy. This theory of the different forces really being one kind of force echoes Hawking's dream of a unified theory of physics, showing he is not alone in his quest.

The fourth type is the strong nuclear force. This holds the atom together. The gluon, a particle of spin 1, carries this strong nuclear force and interacts only with quarks and itself. This force exhibits confinement, meaning all types of particles that create a structure (for example quarks, which come in different "colors," red, green, or blue) must add up to a white color, meaning one each of the three colors must be involved. This can also create unstable particles, such as mesons, which are made when quarks join with antiquarks. These fit the no color rule (they are white, e.g. because a red particle joins with an anti-red one), but the particle and anti-particle pair can annihilate each other, creating other particles in the process. Quarks and gluons can therefore not go about alone and unconnected, as they have color, and particles must be "white" to be stable. At high energies, the strong nuclear force becomes weaker, and quarks and gluons can start to pull free.

The strong nuclear force has a particular rule called confinement, which means that only certain types of quarks can form together to create a particle. Quarks each have a kind of color, which is simply a way of referring to their properties, rather than a specific color. When joining together, these colors must all be present to cancel out and be stable, called "white." This can also be achieved by a quark of one color joining with an anti-quark of the same color, though this is still unstable because particles annhiliate when meeting their anti-particles. In short, after finding out about quarks and their different properties, scientists wanted then to find out how they all relate.

Grand unifying theories try to bring the last three forces together, though the name doesn't quite fit as they don't include gravity. The idea is that at some high energy, the strong nuclear force would be weakened, and the electromagnetic and weak nuclear force would strengthen, so that all three would be equal. In this theory, they could thus be different types of the same force.

This theory of finding the unifying properties of these forces again echoes Hawking's mission to unify all of physics. Even the current road block is the same: integrating gravity. It seems, gradually, all theories are progressing down the same road. At some point, there ought to be a destination.

The grand unification energy, as it is called, is not known. It cannot be tested, as a particle accelerator with enough power to do so would have to be the size of the universe. But scientists can test low-energy outcomes of the theory. For example, protons could spontaneously decay into smaller particles. But the probability of that is very low, and it has never been observed.

For now, scientists can only theorize, rather than prove this idea of a grand unifying energy that will make all the energies act the same. Observing this effect is beyond their reach, but that has never stopped humans from theorizing before.

How humans beings came to be is possibly due to the reverse process—the *production* of quarks and protons. If there were regions of anti-matter (made of anti-particles), there would be a lot of radiation given off at the border with other regions, where particles would meet anti-particles and annihilate, giving off energy. The universe must therefore be mostly matter or anti-matter, or all the collisions and annihilations would leave very little matter behind. It is possible the early universe had an equal amount of each, but the laws of physics do not apply to matter and anti-matter in the same way, resulting in the imbalance we see today.

Returning to the question of how humans came to be, Hawking highlights the fact that all these advances in science and technology essentially come from humans' desire to understand their universe, in turn, because of the desire to understand their place in it. By applying the logic Hawking states here, humans can determine fundamental truths about the universe, which, crucially, is supported by the observable universe.

The laws of physics can obey certain kinds of symmetries. Symmetry C refers to the laws applying to particles and anti-particles in the same way. Symmetry P is the laws being the same in a mirror image situation, for example a particle spinning clockwise or anti clockwise. Symmetry T is laws having the same effect if the passage of time is reversed.

The reason for the imbalance in particles and anti-particles in the universe relates to these symmetries that Hawking outlines. Having determined laws that describe the universe, scientists have also thoroughly quality checked them to see how they hold in all situations.

In 1956, Tsung-Dao Lee and Chen Ning Yang found the weak nuclear force does not obey symmetry P. This was proven true by Chien-Shiung Wu, who caused radioactive atoms to spin in a magnetic field, first one way then the other. More electrons were given off in one direction than the other. Lee and Yang won the **Nobel Prize** for their idea.

Lee and Yang suggested the weak nuclear force does not have the same effect on particles moving in the opposite direction, which Wu proved by causing electrons to do exactly that—a direct link between curiosity, ingenuity and discovery. In contrast to the Penzias and Wilson example, Lee and Yang won the Nobel Prize for their suggestion, rather than Wu for her work in proving it.

The weak nuclear force also does *not* obey the symmetry C, meaning it would cause a universe of anti-particles to not behave like our own. But it does obey the combined CP symmetry—meaning a mirror image antiparticle universe would develop in the same way as our own. Any theory that obeys the general theory of relativity and quantum mechanics must follow the symmetry of CPT. J. W. Cronin and Val Fitch proved the universe does look the same when following only the symmetry of CP, that is, swapping particles for anti-particles and taking the mirror image, but *not* when reversing time. Therefore, the laws of physics do *not* follow the symmetry of T, the reversal of time.

Uncontent with understanding the laws of physics in this universe, physicists analyzed whether those laws would hold in alternate scenarios, where the universe was comprised of anti-particles rather than particles, or developed in a mirror image of our own. One mathematical theory on the unified theory of physics says it ought to follow the symmetry of CPT, all three symmetries, but the laws of physics do not have the same effect when time is reversed, indicating there is work still to be done to understand this unifed theory.

As the universe expands and cools, forces that do not obey the symmetry of T cause more anti-electrons to become quarks than electrons to become anti-quarks, creating the matter we see today. Of course, they are only named that way because they are the majority. If it were the other way round, the names would be exchanged also.

By expanding on these theories, Hawking argues that scientists should not focus only on the universe they can see, but should take a step back in order to look more objectively. In an anti-particle dominated universe, scientists would call the dominant anti-particles just regular particles. Looking at hypothetical universes thus aids in assessing this one without prejudice or assumptions.

Grand unified theories of these forces have not yet incorporated gravity. But gravity is a weak force and doesn't factor much on the atomic scale. Yet, because its effects build up, for large structures, gravity wins out, which is why it creates the universe's structure. Stars' gravity eventually causes them to collapse, and it is what happens in that time, when they become a black hole, that draws general relativity and quantum mechanics together.

Gravity seems to be the problem child of physics—it has yet to be incorporated into grand unified theories of the forces, and is (so far) incompatible with quantum mechanics, making a unified theory of everything currently unreachable. Hawking links into the next chapter, promising to show more about this uncooperative force.

CHAPTER 6

John Wheeler came up with the name black hole in 1969 to describe an idea that had been around for around 200 years. In Newton's time, people argued whether light was a particle or a wave, and how gravity would therefore affect it. Under quantum mechanics, scientists know it is both. Gravity will affect light the same way it does all other particles. Roemer showed that light has a specific speed, rather just traveling infinitely fast, so gravity could have significant effects on light's movement.

Hawking provides a catch up summary here, focusing more on those concepts directly relevant to the black holes he is preparing the reader to consider. As seen already with other concepts, the idea of black holes were around far before the scientific knowledge to back them up, let alone the technology to detect them. Humanity's curiosity about black holes had not died out before an approach was devised to understand them.

John Michell's paper in 1783 first suggested the idea of black holes, though he did not use the name. He said that any star that was big and dense enough would have such a strong gravitational pull that light could not escape it. We cannot see them, but we should be able to detect them due to their gravitational effects. Laplace made a similar suggestion at a similar time, but wrote it out of later editions of his book. Perhaps the idea was too ridiculous.

Laplace's back tracking on the idea of black holes demonstrates the challenges facing the theory, as one of its own proponents lost heart awaiting proof. Nevertheless, the idea has survived since the late 1700s, reflecting the staying power of logical suggestions, regardless of their difficulties in gaining immediate mass acceptance.

But one cannot compare light to other matter that gravity drags in, like a cannonball falling back to earth. Light travels at a fixed speed in one direction. Einstein's general relativity helped to explain this, although it took decades for the relevance to be applied to black holes and massive stars.

Gradually, more theories were established that could support the reasoning behind and offer further exploration of the idea of black holes. Again, Hawking emphasizes the slow build up behind establishing black holes as a valid theory, one dependent on the many discoveries made previous. Scientific understanding is a process dependent on sustained curiosity and on each interconnecting link in the chain, for now.

A star forms when a large volume of gas begins to collapse in on itself under its own gravity—usually it is mostly hydrogen. The increasing number of atomic collisions taking place as the gas contracts causes it to heat up. Soon, it there is so much energy, the atoms fuse instead to create helium. This massive energy creates the star's shine. It also creates pressure, which offsets the gravity, and halts the star's contraction. Eventually, however, the star will run out of fuel. This happens more quickly the bigger the star is, as it requires higher energy and pressure to offset its higher gravitational pull. When it does run out of fuel, it will begin to contract again.

As black holes are born from stars, Hawking first gives the reader a thorough, and fascinating grounding in a star's lifecycle. For the most part, stars spend their life in an existential balancing act. As a massive cloud of burning gas, the star faces the contracting pull of its gravity on the one hand, and the outward pressure of its colliding particles on the other. But this stage cannot last forever, as a star's fuel is finite, so eventually the star's own gravity will overpower its pressure, and the contracting phase will begin again.

While sailing to England in 1928 to work with Sir Arthur Eddington, one of the only people who understood general relativity at the time, Subrahmanyan Chandrasekhar worked out how big a star needed to be to support itself against its own gravity after using up all its fuel. According to the Pauli exclusion principle, matter cannot be in exactly the same place, so nearby particles will repel each other, driving a star's expansion. This can balance against the star's gravity, just as its heat did in an earlier stage.

Familiar with stars' balancing act lifestyle, Chandrasekhar dug a little deeper and found the boundary at which a star's mass determines its fate. Below the so-called Chandrasekhar limit, after collapsing for a while, the star will again find stability at a smaller size because of the way particles cannot be in the exact same place, giving it structure.

But the Pauli exclusion principle only helps to a certain extent, as particles' speed is limited to the speed of light, as light *must* travel faster than everything else. After a certain point, if the star is dense enough, its gravity will outweigh its expanding force. The Chandrasekhar limit states a star one and a half times the mass of our sun will not be able to sustain itself against its own gravity at this stage. Russian scientist Lev Davidovich Landau made a similar discovery at the same time. Stars smaller than the Chandrasekhar limit will become white dwarves, supported by the Pauli exclusion principle between electrons—the electrons repel each other, giving the object structure rather than collapsing. Landau also showed that stars supported by the exclusion principle acting between protons and neutrons would become neutron stars, which are much smaller and denser than white dwarves.

If a star is above the Chandrasekhar limit, this exclusion principle of particles repelling each other is not as strong as the force of the star's own gravity, as the bigger its mass, the stronger its gravity. But smaller stars can balance this out. They can become a white dwarf (a small, cold but still glowing and stable star that has used up its nuclear fuel), because of the repulsion between the electrons in the star, according to the exclusion principle. Or, smaller stars can become neutron stars after collapsing, which are instead supported by the repelling force between the star's protons and neutrons. The fact that Landau made a similar discovery at the same time as Chandrasekhar shows the inevitable progress science will make, as one discovery provides the impetus for the next. Humanity's innate inquisitiveness spurs it onto each subsequent breakthrough.

When a star is above the Chandrasekhar limit it faces serious problems when running out of fuel. It might explode, losing the mass required to remain stable. If it doesn't explode, it will become a black hole and ultimately collapse to infinite density. That shocked Eddington but, when Chandrasekhar won the **Nobel Prize** years later, it was in part for this work.

Eddington opposed Chandrasekhar's finding because it did not fit with his understanding of the general theory of relativity, and as he considered himself the only person since Einstein to understand it, this was most likely hard for him to accept. Indeed, Einstein himself disagreed with the idea of stars collapsing to a point. Facing such opposition, Chandrasekhar shelved the theory, but its validity held out, and years later was recognized by the highest award in the scientific community.

In 1939, American scientist Robert Oppenheimer, took the idea further, though his theories couldn't be proven with technology in his day. Essentially, his work states that stars' gravitational pull changes light's path through space-time. Finally, the light is pulled so strongly, it cannot escape. As light moves faster than anything else, nothing else can escape either. This area of no return is a black hole, the boundary of which is called its event horizon.

Oppenheimer provided the next logical step from the work preceding his own, especially relating to Michell's seminal suggestion that observers would not be able to see such black holes directly. Oppenheimer's work only gained recognition when telescopes became strong enough to provide observational support. Valid theories can survive the test of time, but ultimately must agree with observation to be accepted.

Because time is relative, what happens at a black hole will look different to different observers, such as someone on the surface of the star versus someone at a distance. If an astronaut sent signals to the distant observer on a spaceship every second until the star contracted past the critical radius at which nothing could escape, at 11 a.m., the last signal before 11 a.m. would take an infinite time to arrive because it would not be able to escape the gravitational pull. In fact, each previous signal would take longer and longer to arrive, and the light of the star would appear redder and redder. Finally, at 11 a.m., the star would not allow light to escape at all, and it would appear as a black hole. But the distant observer's spaceship would still orbit the black hole and feel its gravitational affects.

Light from collapsing stars will appear redder and redder as the gravitational force strengthens. This is because light loses more energy escaping the star's surface as the gravity strengthens, lengthening the light's wavelength, which appears to the human eye as red light. Signals will also seem to take longer to arrive as the star's gravity strengthens as the star contracts. Eventually, escape will become impossible, for light, signals, and the astronaut. Given that escape is impossible, scientists can only imagine what black holes would look like on the inside.

Because gravity is strongest at the star's surface, the difference in gravity between the astronaut's head and feet would stretch and then tear him or her apart as the star reached its critical radius. Large regions like galaxies can collapse in similar ways.

If someone were brave and inquisitive enough to want to go see a black hole for themselves, they would not be able to anyway, as they would be torn to shreds before the star hit the critical radius after which it becomes a black hole. Perhaps they are better left imagining.

Penrose and Hawking showed in the late 1960s that there must be a singularity of infinite density and space-time curvature at the center of a black hole. This is similar to the beginning of time at the big bang, but is the end of time for that star, and anything else caught up in it. The laws of science break down in a singularity, but observers outside would not be affected, as nothing can escape from the black hole. Penrose called this notion that breakdowns of science are always hidden from view the cosmic censorship theory.

Penrose's cosmic censorship theory could be said to follow similar logic to the anthropic principle, in the sense that humans cannot see breakdowns in the laws of physics, or else they would be caught up in that same breakdown and die. Thus it is logical that humans cannot continue to experience time (i.e. live) if witnessing that breakdown. Therefore humans continuing to exist will wonder why they cannot personally witness breakdowns in physics.

Some options available within general relativity let the astronaut escape through a wormhole, to appear somewhere else in the universe. But these would be unstable and unpredictable, probably destroying the astronaut in the process. The stronger cosmic censorship theory states the singularity is always in the astronaut's future, as his time ends with it, so singularities are always at the beginning or end of time, as the laws of science break down at singularities, and with them, the concept of time. A black hole's event horizon could be considered a one-way membrane, allowing things in, but not out. Anything that falls in will soon meet the end of time.

General relativity offers a set of equations from which various scientists extrapolate varying solutions. Some of these potential applications include ruptures in space-time that would allow short cuts to other sides of the universe, paths known as wormholes. Also like the anthropic principle, Penrose's cosmic censorship has a stronger version.

General relativity states that moving objects give off gravitational waves, which bend space-time. These waves carry energy away from the object producing them. Slowly, these objects lose energy as the waves take energy away from them, just like how the earth will eventually fall into the sun and become stationary.

Objects cannot emit energy in the form of gravity infinitely. Emitting energy saps energy from the object, which will eventually run out. Energy always has to be accounted for, as determined by physicists' ever more specific calculations.

This process is too slow to see in the earth, but in a system called PSR 1913 + 16, two neutron stars are orbiting each other. J. H. Taylor and R. A. Hulse won the **Nobel Prize** for this discovery in 1993. Just before the stars finally collide in 300 million years, they will be orbiting each other so quickly our current technology would pick up the gravitational waves.

From proposing the idea of black holes, to refining the theory, to determining the alternative outcomes of a collapsing star (here a neutron star), to actually finding them in the night's sky, humanity's continued pursuit of knowledge is slowly but surely unlocking the mysteries of the universe.

The collapse of a star is much more rapid, and what the final stationary form of a black hole would look like was an open question. Werner Israel revolutionized views on black holes by showing that non-rotating black holes would be spherical. Any two black holes of the same size would be identical. One could use Karl Schwarzschild's solutions to general relativity equations to describe them.

Hawking presents science as an ongoing line of open questions. In this case, the question is how to describe the unseeable. Yet, physicists have found a way, thanks to the predictable outcomes of the laws they have discovered.

Isreal thought this meant only a perfectly spherical star could become a black hole, meaning there were no black holes in reality. But Penrose and Wheeler said a non-rotating star's gravitational waves during its collapse would make it spherical. In 1963, Roy Kerr extended this to rotating black holes too. Brandon Carter helped to prove Kerr's and Schwarzschild's solutions in 1970 by showing if a rotating black hole had an axis of symmetry, its size and shape depend only on its mass and rate of rotation. Hawking helped to prove this for stationary rotating black holes. David Robinson later used their work to prove the Kerr solution, showing that black holes settle into a stationary, rotating but not pulsating state after collapse. This means a star of any shape or chemical make up could become a black hole, meaning there could be many of them.

Here Hawking shows how the scientific community comes together to solve problems, by expanding on, challenging, and improving each other's work. Through this collaborative approach, in which any theory can be thrown out at any instant in favor of a more accurate one, humanity's knowledge of the inner workings of black holes (which cannot even be seen) has gradually been streamlined and distilled into a form that the layman can grasp.

Black holes were proposed before they were found. In 1962, Maarten Schmidt found what is now called a quasar, a whole region of a galaxy falling in on itself. In 1967, Jocelyn Bell-Burnell and her supervisor Anthony Hewish found a pulsar, which is a rotating neutron star. It was the first of its kind of be found, and held out hope for black hole believers. Although, at first they thought they might have found alien signals.

Hawking emphasizes explicitly a fact that has simmered under the surface of his narration throughout the chapter: the idea that black holes started life as a suggestion based on no direct, observable evidence. Nevertheless, the math held out, and in the 1960s the scientific community gained its long-awaited first signs of reassurance.

Finding something that we cannot see seems impossible. But Michell suggested in 1783 we can measure a black hole's gravitational effects on the material around it. There are examples of systems where stars orbit some unseen source of gravity. In one case, the minimum mass of the unseen object is far above the Chandrasekhar limit, meaning it is not a white dwarf or neutron star. It is most likely a black hole.

Here, Hawking expands on what, for now, might be the best available proof of black holes, given they cannot be directly seen. As with virtual particles, scientists can deduce the laws of physics based even on what cannot directly be seen, but only indirectly detected. Only the most curious creatures would have patience for this.

More black holes have been found since, and given the age of the universe, there could be more than the observable stars in the sky. The extra mass would explain why the Milky Way, earth's galaxy, rotates. There could also be a very large black hole at the center of the galaxy. Even larger ones could lie at the center of quasars. Objects orbiting such massive black holes would lose matter and energy into it, causing the black holes to rotate in the same direction as the matter orbits it, creating a magnetic field. This would create jets of particles.

With greater confidence that such objects as black holes do actually exist, cosmologists can make better judgments about what they observe in the universe. Black holes might not be viewable, but they do have a visible effect on the matter around them due to their mass and gravitational pull. Astonomers can now factor this into their calculations, driving humanity's scientific progress along further.

There could also be much smaller black holes, with a smaller amount of matter compressed by large external pressure, probably in the heat of the early universe. This would be because the early universe was not uniform—areas of higher density would cause such black holes, as well as the clumping of galaxies. Whether such "primordial" black holes exist depend on the state of the early universe—meaning if scientists can find them, they can determine the state of the early universe.

Finding "primordial" black holes, if *they exist, as well as determining some of their properties, could tell physicists about the state of the early universe. Each discovery, theory, or even suggestion leads to the next big question. No wonder Hawking argues that only when humans know* everything *will they feel satisfied.*

CHAPTER 7

Before 1970, Hawking's work mainly focused on the big bang. Around the time of his daughter's birth, he thought about black holes and their event horizon, a not very well-understood idea at the time, as he was getting into bed. Hawking realized the paths of trapped light in the event horizon could never cross, or they would fall into the black hole. As such, the light at the event horizon must be moving parallel to or away from every other ray. The event horizon could only ever remain stationary or grow.

By situating this particular eureka moment within the humdrum of his daily life—getting into bed—Hawking shows that even at the least obvious moments, the human brain is active and inquisitive. If light waves collide as they attempt to escape a black hole's gravitational pull, they will fall back into the black hole, thus adding to its overall energy. If the event horizon were to contract, it would force light waves' paths to collide, thus feeding the black hole and causing the event horizon to expand again.

This non-decreasing nature of black holes determines much of their behavior. Penrose agreed with Hawking, and they determined a black hole's area could be determined by its event horizon. This non-decreasing idea sounded like entropy, or disorder, which the second law of thermodynamics states never decreases. For example, gas molecules held in one half of a box by a divide will spread into the whole box when the partition is removed. The most *probable* outcome is that particles will spread, and thus increase disorder.

Despite humanity's search for underlying order in the universe, one of its central principles is that entropy, meaning disorder, always increases. Particles tend to mingle, and do their best to spread out in a disorderly (and unpredictable) fashion. Despite knowing and accepting this law, scientists continue in their pursuit of total knowledge.

Jacob Bekenstein suggested a black hole's entropy could be measured by its event horizon. As matter fell into the black hole the event horizon would expand, so sum of the area of black holes' event horizons and entropy outside black holes would never decrease.

Since the total entropy of the universe is always increasing, but scientists cannot get into black holes to measure their entropy, Bekenstein suggested an external measure of a black hole's entropy to allow the laws to hold.

This maintained the law of entropy, but suggested that black holes ought to have a temperature, meaning it must emit radiation—but black holes aren't meant to emit anything. Hawking, Carter, and Jim Bardeen wrote a paper in 1972 to challenge Bekenstein's finding. Hawking partially did so in irritation because he thought Bekenstein's had misused his work. Though, in the end, it turned out Bekenstein was right.

Despite all the examples he provides of stubborn scientists unwilling to let get of their ideas, Hawking finds himself here on the wrong side of science history. Unable to take an objective view due to feeling personally offended, Hawking opposed Bekenstein's work publicly.

Hawking went to Moscow in 1973, where he met Yakov Zeldovich and Alexander Starobinsky. They convinced Hawking that rotating black holes ought to emit particles based on the uncertainty principle. When Hawking later did the mathematics to investigate it, he found even non rotating black holes ought to emit radiation. But, he didn't want Bekenstein to find out.

Hawking could not let the matter go, even when his own work began to agree with Bekenstein's suggestions. This example in particular shows that stubbornness has nothing to do with intelligence or a lack thereof. For Hawking, this had become personal, emotional even, and thus opposing scientific progress despite evidence backing it, can only be an innately human failure.

Hawking finally came round to the idea because the spectrum of radiation emitted would be the same as any other hot body, and black holes seemed to obey entropy. Others have since confirmed the results, and black holes are now known to have a temperature proportional to their mass.

Eventually, the overwhelming weight of evidence for Bekenstein's proposal, which included Hawking's own, led him to accept the idea, which is more than can be said for some stubborn scientists featured in the book.

In fact, the particles emitted do not come from the black hole itself, but the supposedly the empty space just outside the event horizon. This space is not actually empty—there are certain minimum fluctuations and uncertainty. Pairs of particles and virtual particles will appear and collide, annihilating each other. One will have positive energy, the other negative. The real particle is always positive in normal circumstances, but the energy taken to avoid the black hole could make it have negative energy. The negative virtual particle could fall toward the black hole, become a real particle, and no longer need to annihilate with its partner. Both particles might now fall into the black hole, or the now positive-energy former-virtual particle might escape, meaning it appears that a new real particle has been emitted. Smaller black holes are easier to escape, and so seem to emit more particles and glow hotter.

Hawking describes a dangerous dance of particles on the borderlands of the event horizon. Some fall in, but some might escape. The black hole's interference with normal energy distributions disrupts the standard interaction between particles and their virtual particles, which usually annihilate when coming into contact. By disrupting this regular interaction, the excess of particles (that haven't annihilated with their partners or fallen into the black hole) appear to have been emitted by the black hole. Although a little convoluted, to a distant observer, the distinction is trivial.

Positive energy emerging from the black hole would be balanced by the negative energy falling in. According to Einstein's E=mc2 equation, energy is proportional to mass, so negative energy going into a black hole will reduce its mass. Its event horizon would contract, reducing its internal entropy proportionally to the increase in entropy outside. As the black hole contracts it heats up, and gives off more energy, thus contracting quicker and quicker. Finally, it would disappear with an explosion of emissions.

If black holes emit radiation, they must eventually run out of energy. Specifically, this occurs due to the influx of negative energy. In time, then, a black hole's event horizon will contract, with overall entropy still increasing as the black hole emits energy back into the universe. From Hawking's spark of genius while getting into bed, to his refusal that black holes can emit anything, right round to explaining how black holes finally evaporate, Hawking shows how only an objective approach allows and creates scientific breakthrough.

Black holes a few times larger than the sun would be much colder than the general temperature of the universe, so would continue to absorb radiation. Thus black holes will have to wait a long time to emit more energy into the universe than they take in (and in turn contract into nothingness).

With this newly-gained knowledge, physicists can make better estimates about the lifespan of black holes. If a black hole's end depends on expelling its energy, its temperature (a measure of energy) relative to the rest of the universe becomes a key gauge.

Black holes from the early universe would be much smaller though, formed by irregular pressure rather than their own size, and also much hotter. Some would have evaporated already, but some would still be glowing white hot. If humans could harness these early black holes, they could provide immense power. It would be the size of the nucleus of an atom but with the mass of a mountain. One could orbit it round the earth, after towing it through space, but that's not something scientists can achieve yet.

Finally, a potential real-life application of this knowledge about black holes. That said, technology will need to advance considerably before humans are able to draw power from such a "primordial" black hole, if indeed cosmologists are able to locate one in the vast reaches of the universe. Nevertheless, this example shows how expanding humanity's knowledge also expands applications opportunities in the form of technology.

Scientists can assess background gamma radiation in the universe to calculate how common these early universe black holes are. The evidence suggests they are scarce, so the likelihood of finding and harnessing one is low. What's more, our technology would not be able to accurately detect one even if it was near Pluto.

Humans, it seems, are still far from harnessing the power output of one of these black holes. Yet the fact that physicists can describe them in such detail reveals the depths of their interest in every outstanding question.

If such a black hole were to blow up near Pluto, we could detect it, but the likelihood of that happening right now, given that it takes 20 billion years to reach the point of explosion, is low. To see such an event, we have to look out at around a light-year away. Tell-tale gamma ray bursts indicate a uniform presence of such events throughout, or just outside of, our galaxy. Even if we don't actually pinpoint these black holes from the early universe, they still tell us a lot about the time they formed. The universe must have been uniform with high pressure for there to be so few black holes from that time.

Humanity's existence on the earth is just a blip in the ancient history of the universe. As such, it is very improbable that scientists and stagazers will observe such rare events as a black hole exploding so nearby given the length of a black hole's lifecycle (coming after a star's lifecycle). But that will never stop these observers from imagining it, and even measuring such an event in every detail. Doing sp can provide useful evidence for other unsolved questions.

The theory that black holes emit radiation rubbed people up the wrong way, and was the first significant example of general relativity and quantum theory combining. John G. Taylor opposed Hawking when he announced these discoveries. But in the end, everyone agreed that if these two great theories are right, black holes must radiate.

As Hawking had opposed Bekenstein, so Taylor opposed Hawking, but ultimately, theories with logic that stands the test of time and professional criticism gain greater confidence among their proponents. Such theories outlast their opponents.

This new idea about black hole radiation suggests gravitational collapse is not so final after all. Mass or energy lost into a black hole is balanced by its emissions. But is seems when a black hole becomes really small, it will simply disappear. Quantum theory seemed to undermine the idea of singularities, and Hawking's work turned in that direction in the late 70s, focusing on Feynman's sum over histories.

While sound theories might outlast the voices that oppose them, that does not protect scientific theories from being superceded by better, more accurate ones. Since being thought up in the 1700s, humans' understanding of black holes has changed repeatedly, much as prior "knowledge" about the universe has also evolved over time. In providing this further exploration of the nature of black holes, Hawking has also revealed the nature of scientific progress itself.

CHAPTER 8

Einstein's general relativity predicted that space-time began as a singularity in the big bang, and ends in the potential big crunch singularity when everything collapses back in on itself, or in localized singularities in black holes. But when applying quantum mechanics, it is clear that black holes re-emit mass and energy into the universe, eventually disappearing. Applying quantum mechanics to the big bang, then, might change our understanding altogether.

By applying both general relativity and quantum mechanics to the study of black holes, scientists were able to re-evaluate their understanding of the phenomena. This is the draw of finding a unified theory that can incorporate both, as the theory could well change human understanding of the universe altogether.

Hawking's interest in the origin and fate of the universe reawakened while at a conference in the Vatican. The Catholic Church was seeking input from scientists, centuries after making a bad call on challenging Galileo's assertion the earth orbited the sun. At the end of the meetings, the Pope met with scientists, telling them not to enquire too deeply in the big bang, because it was the work of God. Hawking had just spoken on the topic of a no boundary finite universe, which would have no beginning, of which thankfully, the Pope was unaware.

The church's attempt to squash Galileo's ideas came to nothing, as the latter's logic and agreement with observation meant that Galileo's work survived the test of time. Centuries later, it was the church that had fallen behind with the pace of progress, and thus sought input and assistance from the scientific community to catch up. Hawking emphasizes this point to warn of the errors of obstructing scientific progress. Yet, from the Pope's advice not to study the big bang, it seems the lessons has not been learnt.

But first, one should understand the "hot big bang model." This model is a Friedmann model, in which matter cools as the universe expands, meaning the matter has less energy. With a lower temperature, and therefore lower energy, matter begins to clump together as the particles attract each other, because their ability to escape is lower. When particles collide at high temperatures, more particles are produced, while at lower temperatures they are more likely to annihilate with their corresponding anti-particles. Thus, as the universe cools, fewer particles are created.

In this model, after the big bang, particles begin to lose energy (as represented in their temperature) and thus cannot escape attractive forces. Fewer particles are also produced in this cooling phase. It is worth noting this is just one model—scientists have suggested many, and Hawking refers to numerous. Each should be weighed and assessed independently, and each could be thrown out immediately with the introduction of better ideas. This is all part of the process of discovery.

At the moment of the big bang, the universe would have been infinitely dense with zero size, and, as such, infinitely hot. Right after the big bang the universe would have been made up of photons, electrons, and neutrinos, along with their anti-particles, and some protons and neutrons. As the universe cooled, electron and anti-electron pairs would annihilate each other at a rate higher than the pairs were being produced, which creates more photons as a result of the annihilation.

This model has infinities, which as we have seen scientists tend to struggle with. Newton himself couldn't get his head around how an infinite universe would work. Nevertheless, scientists seem to allow these infinities to remain in their models as a place marker, while they expand on the rest of the theory.

One hundred seconds after the big bang, the universe's temperature would be 1 billion degrees, meaning protons and neutrons could not escape the strong nuclear force and began to form into the nuclei of heavy hydrogen atoms, followed by atoms of heavier elements. George Gamow first proposed this model with Ralph Alpher in a 1948 paper.

Scientists can propose fairly specific approximations of the state of the early universe based on the observations made today. Because physicsts understand the strong nuclear force and how it works, they can make an educated guess of the temperatures under which it would begin to command particles, even though it is impossible now to observe the early universe directly.

Gamow and Alpher said radiation from that first hot stage of the universe should still be present in the universe today, which Penzias and Wilson found to be true. Gamow and Alpher's assumption aligns with the large amount of helium in the universe, meaning scientists can be fairly sure their picture of the universe after the first few seconds following the big bang is accurate. After the first few hours, the production of new elements would have stopped, though the universe itself would have continued expanding.

While the early universe cannot be detected directly, Penzias and Wilson's findings demonstrate that knowledge can still be gleaned about the long-distant past thanks to traces still around in the universe today. This gives scientists confidence that their model is accurate, as it accounts for the realities still seen today. Still, the danger of making the evidence fit the theory always remains.

Once the temperature of the universe dropped to a certain point, the electromagnetic force would be stronger than particles' energy to escape it, drawing more particles together to form more atoms. In denser than average regions of the universe, the gravitational force of this clumping matter would have slowed expansion. Some regions would stop expanding altogether and start to collapse. Gravitational forces outside of these regions would, in turn, cause the regions to start spinning, and they would spin faster as they contracted. Soon the spin would balance out with the gravity to stop the collapsing phase, creating disk-like rotating galaxies. There are also oval non-rotating galaxies.

Weaker than the strong nuclear force, the electromagnetic force would come into play at lower temperatures, where the particles lose the ability to escape the electromagnetic pull. With all this clumping, gravity comes into play too, causing isolated regions of contraction, slowing the overall expansion of the universe. These galaxies, as they are called today, often spin due to outside forces, counteracting the gravity. Again, this model works because it agrees with the view of the night's sky, a view that has intrigued humans for millennia.

After more time passed, hydrogen and helium would form into smaller clouds and collapse, due to their own gravity. Contraction would force collisions between atoms, raising the particles' temperature, starting nuclear fusion reactions. This would transform hydrogen into helium, creating heat and pressure, balancing the gravity to halt the contraction of the gas clouds.

Here, the discussion returns to stars, forming with the contraction of gas clouds. The process creates more helium, in turn creating stronger reactions and more pressure to balance out the gravitational force. This understanding of stars' balancing act was crucial to uncovering the mysteries of black holes.

Stars can stay stable in this form for long periods of time, emitting heat and light. Bigger stars will use up their fuel much quicker to balance their gravitational force, creating carbon and oxygen as they contract again. The central portions of the star contract into dense regions, becoming neutron stars or black holes, though this is not yet fully understood. Sometimes outer parts of a star can be blown off, flinging heavier matter out for the next generation of stars or for the forming of planets.

The lifecycle of stars feeds into the lifecycle of planets, with the heavier elements created in the stars' inner nuclear fusion reactors bursting out into the universe to give birth to surrounding planets. Now, understanding stars' balancing act directly links to humans' desire to understand where life came from. Each discovery links to the next, fueled by humanity's insatiable inquisitiveness.

The earth was at first very hot with no atmosphere. Slowly, it cooled and gaseous emissions from the rocks created an atmosphere. Primitive life formed in these poisonous conditions, mostly likely in the oceans, and converted these gases into oxygen. Small errors in reproduction would create new genes, some of which would aid those new organisms in surviving, giving them an advantage over others. This process of evolution led to more complex organisms, including humans, and the atmosphere we have today.

Gradually, the world humans occupy today was formed. This picture is humbling, placing humans in a vulnerable and dependent role amid the long and complex history of the universe. The earth was born of a star born of gaseous clouds somewhere in a rotating galaxy, one of innumerable others. And humans are not the only life form to have inhabited the earth, but one of many in a long line of evolution. Knowing this has not deterred humankind from seeking further answers.

This picture corresponds with the observable universe today, but still doesn't answer why the early universe was so hot, why it is so uniform today, why it expands at so precisely the rate that stops it from recollapsing, and why there are regions of higher density (e.g. galaxies).

Despite this detailed, complex, and humbling model of the universe, humans are still full of questions. Why is it this way, and not another, is the next problem in this ongoing line of interrogation.

General relativity alone cannot answer these questions. Its laws and all laws we have so far break down at the singularity. We cannot know what happened before the big bang. This gives the universe a boundary—the start of time at the big bang.

The theories scientists have today are not sufficient to answer these questions, and Hawking implies a unified theory is required. If the laws of science breakdown at the big bang, it must be considered the beginning and boundary.

God seems to have left a set of rules to determine the universe, within the limits of the uncertainty principle, but how did he decide these laws? We could say we cannot possibly hope to understand his intention. But if the start of the universe was incomprehensible, why can we understand more and more of the universe today? We find the universe is ordered, so that order should also apply to the space-time boundary.

Not only are humans curious, but they are also ingenious. Scientists have uncovered many of the universe's rules, and are confident in their findings because they agree with observation and other theories. Thus, one can assume that the universe is knowable. If scientists can make accurate predictions in certain areas, it follows they should be able to in all areas. Hawking notes that just because humans understand the world, that does not preclude the idea that God made it in the first place.

One answer is the theory of chaotic boundary conditions, which assumes there are infinite universes or that the universe is infinite. The theory assumes the initial state of the universe was completely random, creating an irregular and disordered early universe. It is hard to see how such an early universe would become more uniform like our own, and how there are not more black holes dating from that early period.

While Hawking discusses the idea of chaotic boundary conditions, he notes that this model does not accord with the observable universe, meaning the theory can be assessed for useful components, but should not be directly applied onto this current reality. While scientists are free to use their imagination in their investigations, their theories must ultimately accord with reality.

Even with a chaotic early state, some regions of the universe could have smoothed out, and we could just be living in one of these regions. This is called the anthropic principle. Although it seems improbable that we happen to live in a region or universe that is smooth and uniform, it would only be such regions that support complex life able to ask such questions in the first place. Some people go further to propose the "strong version" of the anthropic principle, which states that in those regions that support life it will seem like those laws were chosen on purpose for the intelligent beings to exist.

The strong version of the anthropic principle borders on religious philosophy, stating that because the nature of the universe is so specifically positioned so as to support life, it follows that it could have been. This approach is born of humanity's desire to place itself in the universe. Thus, while looking at the universe, humanity's role within it is the underlying motivation in such an approach.

Scientific laws contain many numbers that must be measured by observation, such as the mass of certain particles, as scientists cannot predict them yet. One day, there might be a unified theory for predicting these numbers, which seem perfectly calibrated for supporting life. Alternatively, perhaps life formed around the rules in our universe, or our region of the universe. But it still seems there could only be a narrow range of possible configurations of the universe that allow life to form. This could be seen as the divine purpose in the universe, or the strong anthropic principle.

Hawking holds out hope that a unified theory of everything would explain why these numbers are at the exact level to support life. In the meantime, people turn to religious theories, or rely on the strong anthropic principle. But Hawking suggests that only by knowing *why the universe is the way it is, which is so fine-tuned to support life, will humanity's curiosity be satisfied.*

There are many challenges posed to the strong anthropic principle. First, if there are other universes, we cannot detect them and they do not seem to affect us, so we don't need to factor them into our theories. Further, there cannot be different laws in different regions of the universe, or we could not move between them. Second, the wider universe has no direct bearing on our existence, so there is no basis on which to claim it exists for us.

Hawking shows the strong anthropic principle divides opinion. He only describes the notion rather than directly backing it. Here, Hawking shows that simply accepting a theory that seems to make sense is still not a scientific approach. Challenging new ideas os not the same as unthinking stubbornness. Thinking people ought to thoroughly assess all theories' worth and accuracy.

To answer these questions, we need to know the make up of the early universe. In the hot big bang model, it seems there was not a uniform temperature in the early stages, as there was not time for heat to move throughout the universe. The make up of the universe we see today seems to have been precisely chosen if it has to fit the hot big bang model. This could be hard to explain other than to say simply the universe, and we, are the creation of God.

To make the observable universe fit with the hot big bang model, the universe would have needed to develop in very specific ways for it to reach the point that it could support life. This could support religious belief, or question the veracity of the model itself. Science must continue searching, it seems.

To explain how the universe might have started from many different initial situations but still emerged in a uniform manner like we see today, Alan Guth said the early universe might had expanded very rapidly. In fact, he said it could have been inflationary, rather than the deflationary expansion seen today. This inflationary idea states that while expanding rapidly, particles had enough energy for the strong and weak nuclear forces and electromagnetic force to be unified in a single force. As the universe cooled, these forces broke their symmetry from each other, meaning they no longer act in the same way, and appear to be different forces altogether.

Referring back to the earlier idea of symmetry breaking, at the high energies during the rapid expansion, the three unifiable forces (minus gravity) would act as a single force. Later, as the universe cooled, meaning overall energy levels were decreasing, these three forces would begin to operate in the different manners seen today. This idea of unification, referring only to these forces, rather than all of physics, still reflects Hawking's wider dreams of understanding all of the universe with just one set of rules.

But, Guth suggested that just as water can super cool—pass freezing point without actually freezing—perhaps these forces could avoid symmetry breaking too as the universe cooled. This would give the universe more energy than if the symmetry had broken. This extra energy has anti-gravitational effects due to strong repulsion, acting like Einstein's cosmological constant. These areas would increasingly expand, with the space between particles expanding and smoothing out the region, much like the expansion of a balloon smooths its wrinkles.

Hawking offers the simple visual aid of a balloon as an example of the universe expanding, again, having previously repeated Friedmann's use of the analogy. It fits well, and every reader has seen a balloon expand, though no one has directly observed the universe expand. The human imagination is strong and draws direct parallels between two completely separate events.

Guth's model, where expansion sped up for a period, allows time for light to travel across the early universe, meaning different parts of the universe could have the same properties. It could also account for the universe still being at the critical rate of expansion, without assuming divine input.

Nothing can travel faster than the speed of light. Therefore, finding a model where light can travel across the universe opens up the possibility for other forces or effects to spread across the universe too, meaning it could be more uniform. This explanation could replace the need for a deity to control this process.

This would also account for why there is so much matter in the universe. According to quantum theory, particles can be created by energy, which raises the question of where the energy comes from. In the universe, there is exactly zero energy, because positive charges balance negative charges. All matter has positive energy, and thus repels other matter; at the same time the gravitational force attracts all matter, and so could be said to be a negatively charged force as the particles expend their energy to escape its pull.

Positive cancels out negative, meaning the universe is balanced at a sum total of zero energy. Matter, however, always has positive energy (unless falling toward a black hole, as seen earlier). As gravity acts in the opposite way to particles, drawing other objects in rather than repelling them, it can be said to be a negative form of energy.

If the size of the universe doubled, its energy still amounts to zero. In the inflationary model, the energy density remains constant despite the universe expanding, so the overall energy constant is not violated. But in the current universe expansion phase, the energy density lowers. In the inflationary expansion, the universe expands very quickly, and the overall energy available to particles is very large.

No matter how much matter there is in the universe, positive energy will always cancel out negative. But particles have access to greater overall energy in the inflationary expansion phase suggested by Guth.

Just as water always does eventually freeze, so would the symmetry eventually break between the strong nuclear force, the weak nuclear force, and the electromagnetic force. This would bring the universe back to the slower rate of expansion and cooling seen today, and explains how the universe came to be uniform despite a range of possible, chaotic beginnings.

Guth's model actually encompasses many potential initial models of the universe. His intention was not to set out exactly how the universe looked immediately after the big bang, but to offer an explanation of how the current make up of the universe could be made far more probable by showing this current outcome was possible from many different original configurations.

Guth's original theory imagined bubbles, or different regions, of matter slowing at different rates. He said these bubbles would eventually all join up. But many people, including Hawking, pointed out they'd be moving too fast to join up. At a lecture in Moscow in 1981 where Hawking discussed this, with the aid of a graduate student, he met Andrei Linde, who said our entire universe could be one of these bubbles. Hawking later showed the bubbles idea wouldn't work at all, mathematically, but encouraged Linde's work nevertheless. Hawking published a paper with Ian Moss at the same time to resolve the issues with the theory.

In a reversal of the usual situation of a new, good but challenging idea coming out and facing severe criticism from obstinate opponents, here Hawking shows the value in supporting clever but flawed ideas to drive forward the overall progress of scientific development. Taking a mature and objective approach, Hawking backed Linde's work so the valuable portions could be shared, as well as to encourage a budding new scientist.

Paul Steinhardt and Andreas Albrecht proposed similar ideas to Linde's at a similar time, and are given credit with him for the new inflationary model, based on slow-breaking symmetry. The ideas are still discussed, but have been largely discredited, as we ought to see more differences in background radiation than we do.

Some continue to use Linde's and his counterparts' concepts, but Hawking shows the tide of scientific discovery has already begun to leave these suggestions behind amid the unstoppable pursuit for greater knowledge.

Linde put forward the chaotic inflationary model in 1983, which said there would be spin-0 in certain regions that, "because of quantum fluctuations, would have large values in some regions of the early universe." The energy in those fields would have anti-gravity effects, like a cosmological constant, increasing the rate of expansion. The energy would slowly decrease to the rate we see in the big bang model. One such region could be the observable universe.

Linde's work was not wasted. As seen with many other theories, his inflationary model provided the impetus for more accurate deductions. He was not put off by earlier failures, and his curiosity did not diminish, as proven by his return with a more complex model only a few years later.

This new model left open a range of early universe configurations that would still result in the uniform universe seen today. There would still be starting points from which our universe could not have arisen, however, meaning we might still have to turn to the anthropic principle.

Like Guth's work, Linde's opened up more possibilities for the early universe's initial configuration. Instead of simply accepting the anthropic principle, which does not provide direct knowledge of, or measurable laws governing the early universe, these scientists rethought the models themselves to find a better fit.

To *know* how the universe started, we need laws that hold at the beginning. General relativity relies on singularities, which involve the break down of scientific law. Really, what singularity theories show is that gravity becomes so strong that we need to return to the quantum level, and use a quantum theory of gravity.

Humans are driven by a desire to know *the universe, not just get the general gist of it. Otherwise scientists would have lost interest long ago, and the funding would have long dried up. Instead the quest continues, and as Hawkign states here, the best path is to find the unified theory of everything, which will settle the matter once and for all.*

There is no consistent theory that combines quantum theory and gravity. If there were, it should involve Feynmann's sum over histories proposal, which states particles move from A to B by every possible path. Scientists know how to measure this, but actually doing the math requires using imaginary numbers. This is a normal mathematical tool, by which numbers can be multiplied against themselves to produce negative numbers, something "real" numbers cannot do: -2 times -2 is 4, but i2 time i2 is -4. If real numbers go left to right on an axis, imaginary numbers go up and down.

This unified theory has not yet been found, but scientsts can tell which key theories it must feature. The sum over histories proposal changes science's approach from attempting to exactly map out the history of the universe, to understanding the most probably course of events. Here, Hawking introduces the tool of imaginary numbers, aptly named in that it powers the human mind to calculate largely unobservable situations.

To calculate sum over histories, one must use imaginary time, that is, imaginary numbers to represent time, which clears away any difference between space and time. Euclidean space-time (so-called after Euclid, the Ancient Greek who founded two-dimensional geometric studies) is four-dimensional, but really the device is just used to do the math.

Using imaginary numbers to represent imaginary time to calculate events in curved, four-dimensional space-time that does not appear the exact same as the universe does to human eyes, demonstrates the human brain's lateral reasoning abilities, applied in the pursuit of ultimate knowledge.

Another feature of the unified theory of quantum mechanics and general relativity is that gravity is represented in a curved space-time. Applying the sum over histories to Einstein's ideas on gravity, the history of a particle is a complete curved space-time that represents the whole universe. To find a space-time that is really possible, one adds up all the wavelengths of all the associated possible particle histories of that universe.

The second key theory that must be incorporated into any unified theory of physics is gravity, and when comined with the first key component, sum over histories, the math starts to become a real challenge, accounting for all the wavelengths of all the possible histories of particles in the universe. Hopefully any unified theory would help to simply this approach.

In both quantum and general relativity theory, if we know the make up of the universe at the beginning, we can know the history and state of the universe now. Under general relativity, the universe can only be finite or infinite in time. But quantum theory adds a third option: that the universe could be finite, but with no boundary, like the earth's two-dimensional surface. In this model, there would be no need for singularities, or for God. The laws of science would not break down. The universe would just *be*.

Hawking introduces a third option—that the universe could be finite in space but with no boundary. Just as one can walk around the earth and come back to the starting point, so a ship could travel around the universe in one direction forever, coming back round on itself. There would thus be no beginning or end, and no need for a creator.

Hawking first put forward this idea at the Vatican conference, but its implications for a beginning and therefore God were not understood. He spent the next summer working with Jim Hartle in the U.S. on this idea, and back in the U.K. with Julian Luttrel and Jonathan Halliwell. The idea remains a proposal, and making predictions with it remains complex because the math is beyond current abilities.

Hawking was brave, then, to report on this potentially atheist idea at the Vatican, the center of the Catholic Church. He emphasizes that it is an idea, because it lacks the basic feature of any good theory—being able to make observably correct predictions. That has not stopped Hawking from investigating the idea further.

Each sum over histories history offers a comprehensive account of space-time and its contents. Again, the anthropic principle can explain why one history is right rather than others—we know we exist, so life must be involved in the model. But it would be preferable to *know* which history is the most probable.

Although there is reasoning to allow a "good enough" approach, Hawking stresses that knowing *that science has found the* right *answer is the only way to settle the inquisitive human mind. Double checking seems a natural urge and fair demand.*

One group of histories turns out to be more probable than others. The histories of the universe would expand and contract, just as the lines of latitude circling the earth get bigger as one moves away from the North Pole (equivalent to the universe's starting point) and toward the equator (the universe's maximum size). These lines of latitude then contract again as one moves on toward the South Pole. The poles are not singularities in this model, which uses imaginary time as the axis from pole to pole, though they may seem like them in real time.

Hawking uses the image of the three-dimensional globe to represent the expansion of the universe. The distance traveled from the North Pole represents the progress of imaginary time, so even after the universe hits its widest point at the equator and begins to contract again, imaginary time is still progressing in the same direction. The key argument of this model is that the poles are not singularities, just points.

It seems, there might be no singularities in imaginary time, undoing Hawking's earlier work. But, singularity theories showed gravity to be so powerful at these points that it had to be considered on the quantum theory scale. Singularities will only appear as such in real time, but one could equally say maybe our real time is the imaginary time, if imaginary time doesn't have singularities. Perhaps imaginary time is more simple, and our real time is just a helpful way to explain what we see. But all theories exist only in our heads. So this question is pointless, and one can use whichever is most helpful in each situation.

Hawking discusses theories that undermine his own work, accepting that outdated ideas must be left by the road side on the journey toward total understanding of the universe. He also points out that if real time blocks our understanding of the universe, the sense that it is "real" at all begins to crumble. If imaginary time provides the perspective with which to properly understand phenomena such as black holes, it begins to seem less imaginary.

By applying the sum over histories and no boundary theory, one can find which characteristics of the universe are likely to happen together. The no boundary theory predicts it is very probable the current rate of expansion is uniform across the universe, for example. This is backed up by Penzias and Wilson's discovery of uniform microwave radiation.

The no boundary theory does have some predictions scientists are able to confirm, and already have. Penzias and Wilson's Nobel Prize seems ever-more well-earned here, with another proven theory tucked under their belt. Such are the rewards of following up on loose ends.

Work is ongoing on the small differences in the early universe that later created the galaxies, and so on. The uncertainty principle tells us there was a minimum level of fluctuations, and the no boundary theory tells us the early universe must have been not uniform at exactly this minimum level. The universe then rapidly expanded, which would have amplified any non-uniformities. This agrees with observation that density varies from place to place, creating galaxies and people.

Hawking shows in this chapter, as highlighted in this small summary, that science has come a long way toward understanding how humans came to exist. By mapping out the potential histories of the early universe, and finding the most probable development patterns, humans have come closer to understanding their own place in the complex history of the universe.

The idea that space-time has a closed surface with no boundary seems to eliminate the role of God. People thought the fact that we can discover and know the laws of science does not preclude a creator, who now chooses not to intervene. But if there was no beginning, how was there a Creator?

In the no boundary model there are no singularities at which the laws of science break down, meaning everything can be measured. Also, Hawking adds, a no boundary universe would have no beginning or end, so no big bang. With a decreasing amount fo unknowables in the universe, the space left for God is growing ever smaller, emphasizing how religious thought is increasingly left only in the areas science cannot yet account for. That is, science is slowly replacing belief.

CHAPTER 9

The early 1900s saw the abandonment of the idea that everyone would be able to agree on the time an event took place, provided they had a good clock. After the speed of light was found to appear the same to every observer, time was determined to be relative, just like space.

The fact people were willing to accept the challenging idea that ime is not the same for everyone, meaning it is not "absolute," shows the general climate of thought in that day. Science has earned people's trust, and new ideas were more likely to gain wide acceptance.

To unify gravity with quantum mechanics, one must apply imaginary time. Imaginary time is no different from the dimensions of space. You can go back and forth in imaginary time, just as you can head south or turn back north. But in real time, there are real constraints on how we move through time.

Unifying two of the most central concepts of modern science requires stretching the imagination into previously unchartered realities—imaginary time. Navigating in imaginary time is actually easier, suggesting that once a unifed theory of physics is found, other unimaginable realities will become navigable.

Scientific laws obey the combined symmetries of C, P, and T. C refers to particles acting as anti-particles do. P refers to their mirror image. T refers to reversing time. Scientific laws will be the same in the symmetry of C and of P, meaning mirror-image anti-matter people would live in a mirror-image anti-matter universe that resembled ours.

Returning to an idea previously discussed, Hawking recaps the different types of symmetries that the laws of physics are thought to follow. Again, this is something like entering imaingary territory, analyzing how the universe, or just one situation, wold unfold in different but symmetrical circumstances.

But the laws of science do not run the same if you run time backward instead of forward. Just think of a glass falling off the table and smashing. You would not see it jump back up and re-form. This is because of the law of entropy, which states that disorder in any system will usually increase as time goes on. A smashed cup is disordered, and does not reassemble itself back into order.

Time, however, always seems to run one way in normal situations, and its direction matters when considering the laws of physics. The concept of entropy links to time, because disorder tends to increase in any system. This is not a certainty, but the overwhelming likelihood.

Entropy, a concept defined in the second law of thermodynamics, directs the first, thermodynamic, arrow of time. Second is the psychological arrow of time, which is the direction we feel time passing, as we make memories. The third and final arrow of time is the cosmological arrow, which is the direction of the universe's expansion. These determine the direction of time.

Because disorder always increases, entropy can be considered an arrow of time, directing and indicating its movement. Another is humanity's observation of time, and the third is the universe's development trajectory. For humans, time is not an assumed property of the universe, but a measurable and complex question.

Hawking suggests the no boundary universe model and the weak anthropic principle explain why these three arrows all point the same way, and why they exist at all. The thermodynamic arrow determines the psychological arrow, so they always point the same way. The cosmological arrow, however, will not always point the same way, though it does right now. When the three do point in the same direction, however, the universe is suitable for life forms able to ask why the three arrows all point in the same direction (the anthropic principle).

Luckily for the reader, Hawking has an explanation to offer for why these three arrows of time are currently pointing in the same direction. The anthropic principle is a key aspect of this approach, as all three arrows must necessarily be pointing in the same direction to allow life to form, as Hawking will explain. But, as before, this alone is not a satisfactory explanation for inquisitive humans.

The thermodynamic arrow relies on the law of entropy, which states disorder becomes more likely as time goes on. Imagine a jigsaw box in which all the pieces start off in the ordered places to form the picture on the front of the box. The more someone shakes the box, the more likely it is the pieces will separate and become more disordered. It is possible the pieces would fall back into the original, ordered state, but this is far less likely. If the reverse was true, and disorder decreased with time, broken glasses would jump back onto tables and repair themselves.

Increasing disorder, or entropy, is an inherent feature of the universe, as evidenced by the day-to-day examples Hawking provides. Despite being such a normal occurrence, just as familiar as apples falling to the floor, the fact that disorder nearly always increases has caused humans to ask why events occur in that order, rather than the reverse.

For the psychological arrow of time, the process of making memories creates more order internally, but the energy used to create memories is emitted outward, creating more overall disorder. This means humans, and computers, only remember things in the direction of entropy, making the psychological arrow of time almost trivial, as it is determined by the thermodynamic arrow. Humans remember and measure time in the direction that disorder increases.

This inherent concept of entropy holds true even in the process of recording time, as based on the thermodynamic arrow, fusing the two together. These two arrows will always point in the same direction as one depends on the other. This idea seems ironic, as humans' strongest sense of time, memory, is the weakest of the three arrows of time, Hawking argues.

General relativity cannot tell us what happened at the very beginning or what happens in singularities, because there the laws of science break down. The universe might have been smooth at first, but it might also have been lumpy and disordered. If the universe was completely disordered, the thermodynamic arrow might well point the opposite way from the cosmological arrow, but that is not what we observe. One requires a quantum theory of gravity to *know* how it all began, rather than guess.

Hawking returns to the fact that humans still do not know for certain how the universe started or what it looked like in its earliest stages. This is a great, open question that he believes will only be solved when a unifying theory of physics unlocks the answers on the final mysteries of the universe. Until then, humans will continue to wonder, but also work toward potential theories.

The no boundary principle does away with singularities and edges, meaning the world is finite, smooth and uniform, to the extent the uncertainty principle allows. After a period of inflationary expansion, regions would slow their expansion and begin to clump, forming galaxies, stars, and people. In this way disorder increased, creating the thermodynamic arrow of time, pointing the same way as the cosmological arrow of time, or the universe's expansion.

The universe cannot be perfectly uniform because the uncertainty principle states there in an inherent randomness in everything. Thus, disorder is always increasing in the expansionary phase of the universe. That means the universe's expansion can be considered an arrow of time, and one that coincides with the thermodynamic arrow.

The question then arises as to whether disorder decreases as the universe begins to collapse—would the thermodynamic arrow reverse as the cosmological arrow does? At first Hawking believed so. He thought the universe would return to a smooth and ordered state when it shrunk. This would also make it the time reverse, he thought.

Having determined the three arrows of time, more questions, inevitably, arose. Hawking wondered, would the universe's contraction phase be the mirror image of its expansion? If so, this would suggest a total reversal of time as the universe retraced its steps.

But a colleague Don Page pointed out to Hawking the contraction phase did not have to be the time reverse in the no boundary model. Also, Hawking's student, Raymond Laflamme, discovered the contracting phase should look very different to the expanding phase, and so Hawking changed his mind. Disorder ought to continue to increase when the cosmological arrow reverses and the universe begins to contract.

In the end, Hawking decided that disorder would continue to increase during the universe's contraction. This means that the cosmological arrow of time will reverse, but the other two will continue to point in the direction that disorder increases.

Hawking had to admit his mistake. When Eddington opposed black holes, he did so because he could not admit a mistake. Others often pretend they had never made the mistake in the first place, and pretend it never happened. But Einstein gave a better example when he called the cosmological constant the greatest regret of his life.

When it becomes clear that a scientist has made a mistake, he or she has two options: deny or accept that fact. What Hawking shows here is these options reveal scientists' priority: protecting their own ego, or advancing the progress of science.

Hawking wondered, if disorder always increases, and the psychological arrow follows the thermodynamic one, then why does the cosmological arrow happen to point toward expansion and not contraction? The anthropic principle offers one answer, as conditions within the contracting phase would not be conducive to life (as all stars would have burned out), so we end up asking why we exist in the expanding phase, when it is the only period capable of creating life.

The anthropic principle offers, again, an unsatisfactory answer. It follows that intelligent life living in a time when the three arrows of time all point in the same direction would wonder why it happens to be that this is the case. But Hawking wants to specifically know why the other options are off the table.

At the turn of the contracting phase there would be no strong thermodynamic arrow as the universe would be in almost total disorder. Yet life requires the thermodynamic arrow, as it breaks down food (ordered forms of energy) to live, creating heat (disordered energy). The expansion doesn't drive disorder, but the no boundary condition means the thermodynamic and cosmological arrows must point the same way to support intelligent life.

The process of supporting life involves breaking down ordered forms of energy to power living organisms. That energy is emitted, for example as heat, back into the universe in a more disordered format. For the universe to approach its contracting phase, it must be in a state of near total disorder, meaning there is no first arrow of time at all, and no ordered energy for food or fuel, meaning life cannot be supported.

The laws of science do not distinguish between the forward and backward direction of time, but the three arrows of time do. Human understanding has created order in a small corner of an ever-more disordered reality. By reading this book, you will have created order in your own mind by creating new memories, but the disordered heat used to power your body and radiated into the world will outweigh that order many, many times.

Hawking argues that humans strive for order, as reflected in their pursuit of a theory to categorically explain everything. Yet this mission cannot ensure actual order in the universe. The very attempt creates more disorder, as an inevitable trend that characterizes the universe.

CHAPTER 10

In the past chapter, time was like a railway line where you could only travel forward. But maybe there are loops and branches, so even if you can only go forward, you could retrace your steps or double back, meaning you could time travel. Like many things that were once science fiction, it could become a reality.

With a better understanding of how time and space works, humans can indulge in imaginary scenarios that could potentially not be all that imaginary after all. Science fiction is increasingly becoming reality.

Mathematician Kurt Gödel suggested a new model of space-time in 1949 under general relativity. He said the whole universe was rotating in the direction spinning tops point. As a side effect, you could set out in a spaceship and return before you left. This annoyed Einstein, who didn't want time travel as part of his theory of relativity. This also doesn't match observation, as the universe does not rotate.

While Einstein could humble himself over his erroneous cosmological constant proposition, he did not like other people messing with his theories, which Hawking mocks with ironic language in his description. Nevertheless, Gödel's model was unviable anyway, somewhat sparing Einstein's reputation.

Other space-times allowed by the rules of general relativity do allow for time travel, and fit what one can observe in the universe. For example, in the interior of a rotating black hole, or a space-time where two cosmic strings move past each other really fast. These cosmic strings could have formed in the early universe as a result of symmetry-breaking, and hold such high tension they can propel vast objects at high speeds in milliseconds when they straighten out.

Gödel's defunct model did not kill off the idea of time travel altogether, perhaps because humans found the idea simply too good to give up. There are other models that allow time travel, of varying dubiousness.The cosmic strings mentioned here are different from the string theories mentioned in the next chapter.

In the Gödel solution and the cosmic string space-time, the universe was so distorted in the beginning that travel into the past was allowed. But there is no reason to believe God created such a chaotic reality. The uniform microwave energy and the abundance of light suggest the universe was not so chaotic and curved near its beginning to permit time travel. This would also be true in the no boundary condition. The question follows whether we could *warp* space-time enough to permit time travel.

Hawking remains skeptical about the theories mentioned so far. He invokes God in a casual way, equating the creator's will with the order apparent across the universe. Thoughts like these appear often throughout the text, in an attempt to not write theist approaches out of science altogether.

When it comes to long-distance space travel, because time is not absolute, an interstellar or intergalactic journey would appear to take much less time to the travelers compared to those back home on earth. But this form of travel into the future is joyless, as everyone the astronauts knew would be long dead. This is only true if you cannot travel faster than the speed of light. If you could, then you could arrive back before you left.

Hawking shows what could be considered future time travel would be possible by traveling long distances. But without the possibility of return, very few would want to attempt it. The story is different if those interstellar travelers are traveling faster than the speed of light.

If a space ship travels from event A to event B below the speed of light, all observers will say event A happened before event B. But if the ship traveled above the speed of light, different observers moving at different speeds would have different measurements, and disagree which happened first. It could even be possible to travel back from B, faster than the speed of light, before A happened.

If a space ship could travel from point A faster than the speed of light, then it would arrive at B long before any other information reached B, even information about events at point A before the ship departed.

Exponentially more energy is needed to achieve the speed of light, however, and rockets cannot get enough power to achieve this speed. Perhaps space-time could be warped to allow a shortcut, allowing a wormhole between two regions; this would allow information from B to pass back to A faster than light took to get from A to B the normal way, effectively allowing time travel to the past.

While this possibility of time travel might excite imaginative humans, in reality, no object with mass can reach the speed of light. As such, another approach is required. Shortcuts through space-time would be another good option, Hawking argues. Humans' dreams of time travel can live on.

Einstein and Nathan Rosen were the first to suggest wormholes could exist, hence their other name, Einstein-Rosen bridges. These bridges are unstable and do not stay open long, but an advanced civilization might be able to stabilize one. Matter has positive energy and curves space time like a sphere; negative energy would curve it like a saddle, meaning to create wormhole, one would need negative energy density.

While Einstein opposed the idea of direct time travel, as his theory of relativity stated nothing could travel faster than light, he proposed the idea of wormholes. Such bridges would connect portions of the universe to other distant regions, and, crucially, can be manipulated. If one arrived in a distant region before light had arrived there from one's origin, the effect is the same as time travel.

Quantum theory allows a negative energy balance in certain areas as long as the universe's overall balance is positive. Scientists have detected virtual particles from observing the different pressures applied to metal plates created by discrepancies of the density of virtual photons between and outside the plates. Within the plates, the photons would only occur in the space if their wavelengths matched the width of the space between the plates in terms of whole numbers, otherwise a wave crest at some point would hit a trough and cancel out. So fewer photons occur within the plates, and the higher density of photons outside the cavity between the plates creates inward pressure. The cavity within the plates can be said to have negative energy, while the normal conditions outside have zero energy. This is called the Casimir effect. Along with light bending during eclipses, these observations show space-time could be warped.

Similar to the earlier examples of electron orbits requiring a whole number of wavelengths, and how light wave crests and troughs cancel each other out to create patterns on a wall, scientists can create pressure from manipulating this interaction of wavelengths between photons. In this experiment, negative energy is created between the two metal plates due to the difference in photon density between and outside the plates.As a result, physicists have learned that they can create negative energy, that in turn could create wormholes. Technology will have to improve some way before the process is stabilized, however.

If such time travel is possible, then one might well ask why we haven't met anyone from the future. It could be that the past did not have the curvature required for time travel, but this might not be true of the future. So time travel might be confined to the future, explaining why we haven't seen time tourists yet.

Having discovered that time travel is theoretically possible, the next question is why time travelers have never been uncovered in reality. Hawking offers a possible answer, but only time will tell.

This doesn't explain away the many paradoxes of time travel in to the past, which involve contradictions if you could change the past. One explanation is called the consistent histories approach, which says everything that happens in space-time must be consistent according to the laws of physics. This means you would only travel into the past if history already showed that you had done so. The idea comes down to free will, which is a debatable concept itself if there really is a unifying theory. Such a theory could well determine human behavior, negating the idea of free will.

The reason time travel in science fiction films is always problematic is the issue of paradoxes. Hawking argues that the problem centers around the question of free will, which hangs in the balance on the basis of whether or not scientists are able to find a unifying theory of everything. Such a theory might truly explain everything*, showing choice has never truly been a factor. Thus, there would be no paradoxes as the laws of physics would rule everything.*

Another explanation is called the alternative histories hypothesis. This involves time travelers going back into alternative pasts, with total free will. This sounds like Feynman's sum over histories, which states the universe had every possible history. But, each history would be self contained, so the time traveler would have to travel back to his or her own space-time's past.

Hawking describes a possible time travel scenario where free will is a factor, but he is skeptical traveling into other histories is a possibility. Instead, it seems more likely each time traveler would remain in their own space-time, which would have to remain consistent.

Feynman's sum over histories allows time travel on a miniscule scale. As particles follow the C, P, and T symmetries, a particle going backward in time could be considered an anti-particle going forward in time. For example, black holes "emit" particles, where one component of a particle and anti-particle pair escapes as its partner falls in. The former appears to be created by the black hole. It could also be described as an anti-particle traveling back in time out of the black hole.

When seen from the symmetries approach, the question of time travel becomes one of perspective. Just as imaginary time could be considered the real time if it gives us a better pictures of how the universe works, so too could a particle going forward in time be considered an anti-particle going back in time.

One idea, called the chronology protection conjecture, works in a similar way to the cosmic censorship idea, and suggests the laws of science purposefully prevent large-scale time travel. But this has not been proven. The idea goes, when space-time is warped enough to allow time travel, virtual particles moving in closed loops become real particles moving forward in time, adding to the overall energy density of the universe multiple times, and creating much more positive energy density to outweigh the negative energy created to curve space-time. It is not known what curvature these particles would create, or if it would differ between kinds of particles. The question thus remains open.

Scientists have found inherent balance in the universe. Energy always adds up to zero given the overall balance of positive and negative charges. This can fluctuate in isolated regions, but the overall balance will remain across the universe. Warping space time, however, could unleash new energy density into the universe, thus canceling out any excess negative energy created to try to form wormholes. The matter remains one of humanity's innumerable open questions.

CHAPTER 11

It is too hard to create a theory that covers everything in the universe in one go. So far there are partial theories that focus on different aspects of science. But in the end, it would be good to have a unified theory that covers everything, without having to make up certain numbers for certain aspects to make them fit. This mission is called the unification of physics.

Hawking's central focus throughout the book is how the partial theories that humans have devised so far point toward an overarching, unified theory of physics. He makes a case for having such a unified theory as the best possible option to understanding the universe, rather than making the theories fit certain observations.

Einstein tried and failed to find a theory of everything, mainly because not enough was known about nuclear science at the time, but also because of his own refusal to accept quantum theory despite his own input into its creation. The uncertainty principle, on which quantum theory is based, is fundamental, and must be incorporated into any unified theory.

Even Einstein fell on the wrong side of science history, opposing quantum theory and therefore obstructing scientific progress in this field. Yet quantum theory has become central to modern understandings of the universe, and has since earnt its place next to general relativity.

Over-confidence should be dampened, as there have been false starts before. For example, Max Born asserted, "Physics, as we know it, will be over in six months," after Paul Dirac discovered the workings of the electron. Of course, the discovery of the neutron and nuclear forces just opened up more questions. Even so, science is still progressing toward an answer.

Hawking argues human arrogance is as natural and as obstructive as human obstinacy. Misplaced confidence can distract scientists from the mission just as much as their refusal to accept new ideas. Only objectivity is a suitable approach, amid the seemingly endless questions that arise in the curious human mind.

Previous chapters covered general relativity, incomplete gravity theories, and the three forces that can be combined in grand unified theories, although these do not include the gravitational force. The problem with incorporating the gravity into GUTs is that it does not take into account the uncertainty principle that defines quantum mechanics.

There are many aspects of science that remain in complete or incompatible with other areas. Even supposedly unifying theories of the major forces do not include all the forces. Therefore, there is work still to be done.

Thus, the first step is to combine the uncertainty principle and general relativity. This has already resulted in significant rethinks, such as black holes not being black and the universe having no edges. The problem is that under the uncertainty principle there are technically infinite numbers of particles, which add infinite mass to the universe, and so curve space-time into an infinitely small size.

Hawking again emphasizes the crucial first step of finding a way to intgrate the two great discoveries of the 20th century: the general theory of relativity and quantum mechanics.Other partial theories that account for both of these grand theories have demystified even the unseeable phenomena in the universe, such as black holes.

Mathematically, infinities in partial theories can be canceled out by introducing infinites elsewhere. But this means certain values have to be chosen from observation. The theories themselves cannot predict these values, which is a serious drawback. When incorporating the uncertainty principle and general relativity one can either adjust the strength of gravity or the cosmological constant. But this still will not remove all the infinities from the predictions, which do not match with measurable observations.

Infinities are indications of unknowns, indicating gaps in human knowledge, and work left to be done. The presence of such infinities makes the math less accurate, as certain numbers are chosen from observation rather than explained with a theory, which does not necessarily contribute to definitively understanding *of the problem at hand, nor the solution devised.*

In the 1970s, a possible solution was offered, called supergravity. It combined the graviton, the gravity wave-carrying particle, with other particles with different spin. These were all considered different forms of one superparticle, which unified certain matter and force particles with different spin whose positive/negative energy canceled each other out. But the calculations to see if any infinities remained were too long and difficult to do.

Supergravity was an attempt to unify certain particles with different spin, but it proved beyond humanity's current power to prove mathematically. Ultimately, such theories need to be provable. If the theory can stand the test of time until computers can manage the math, it could gain the confidence of the scientific community.

1984 saw a total change in approach with the creation of string theory. This suggested that particles were not a dot, but very thin lengths with one dimension. They could be open strings with ends or closed strings, like loops. Particles are in one place at one time, and their histories are drawn as a line in space-time. Strings occupy lines in space-time at any one point. This gives it a two-dimensional history called a world-sheet, where one axis is time and the other the position on a point of the string.

Since then, however, string theory was proposed. This involved a complete perspective change on the form and features of particles, which were now viewed as one-dimensional string-like lengths or loops. Scientists devised new graphs to represent the histories of these strings.

Two strings can join, either at the ends for open strings or to create a larger circle for closed strings. They can also divide. String theory replaces the idea of particles with waves down the string. Absorption or emission of energy and particles is represented by the merging or division of strings. Gravity passing from the sun to the earth would previously be seen as a graviton passing from one to the other. String theory creates an H-shaped pipe, where the vertical sun and earth pipes are linked by the gravitational force in the middle.

With this totally new perspective on particle movement and interaction, scientists are almost reworking the basics, such as how energy passes between particles. Hawking describes this process to emphasize the earlier point he made that scientific theories are only used until a new and improved version comes along. The scientists must be ready to reassess any and everything they thought they knew.

String theory first arose in the 1960s, to describe the strong nuclear force. Small particles in the atom were waves on a string, and the nuclear forces between them were strings that formed a web. These strings would have their own tension of about 10 tons.

This reassessment started with the some of the smallest particles, as physicists started to rebuild their knowledge from the ground up.

In the 1970s Joel Scherk and John Schwarz said string theory could describe gravity, but only if the tension were significantly higher. This would leave most of general relativity's predictions unchanged, except on the miniscule level. Their work didn't gain much attention at first. Sadly, Scherk died from diabetes, leaving Schwarz to continue the work alone.

Scherk and Schwarz's suggestion is a type of unification theory, with relevance for both. general relativity and quantum mechanics. Hawking notes that their ideas didn't gain much traction, as the scientific community was busy trying other leads. This is not due to stubbornness, but the sheer amount of open questions outstanding.

String theory came back into fashion in 1984 after supergravity failed to make much more progress and a joint paper from Schwarz and Mike Green on left-handed particles garnered attention. Soon, a new version of the theory, called the heterotic string, arose. These strings could eliminate all infinities, although this is not yet proven. But the biggest problem with string theories is they require either 10 or 26 dimensions.

String theory came back into fashion after other theories fell through or hit dead ends, as the tide of scientific progress must advance. String theory requires significantly more dimensions than physicists have been used to dealing with, but the wide acceptance of the idea shows that modern scientists are willing to consider entirely new approaches.

It is possible we cannot see all these other dimensions because they are curved up into very small spaces. We only see the three spatial dimensions that we are used to because they are fairly flat. If you look at a straw from far away it looks one-dimensional—just a line. Closer up you can identify many more points on the straw. In string theory, looking on a very small scale reveals ten dimensions. No room for space ships, then.

The next question, then, is how to see all these new dimensions that string theory relies on. Hawking provides an everyday example of how more dimension become apparent on closer inspection. Therefore, the next step for scientists is to learn how to look ever-more closely, something they have been doing for centuries.

The question then arises as to why the four dimensions of space and time that we can see happened to flatten out, while the others didn't. Again, the anthropic principle gives a partial explanation. Two dimensional animals could not exist, as they could not form the complex inner systems required to feed themselves.

As with most theories, the question of why the universe has turned out this way, rather than any other, arises. The anthropic principle is always on standby as a go-to response, but as ever, this answer is not satisfactory for those who wish to know why the universe turned out the way it did.

There are also problems with more dimensions. Gravitational forces are increasingly weaker at the same distance with more dimensions at play. This would create instability, causing the earth to spiral away from the sun under the influence of any disturbances. The sun itself would be unstable because its own gravity might not hold it together, and atoms would face the same instability.

There are not only problems with visualizing or locating these extra dimensions. The effect these dimensions have on the laws of physics also raise new issues. The effect these additional dimensions have on the earth's orbit, for example, do not accord with observation. Therefore, many questions remain, but this has not killed the idea. It simply requires more thought.

The anthropic principle suggests life is only possible in space-times with the four flat dimensions we are used to. String theory allows some regions of the universe to have the same properties as ours, while in other regions maybe the other dimensions have flattened out. Though, there may be no intelligent beings in those dimensions.

Intelligent life forms will always wonder why their region of the universe is a certain way, but string theory suggests there could be regions that have more dimensions, and which would not be able to support life. One resulting question would be whether humans would be able to travel to such regions.

Another problem is there are many string theories, and millions of configurations for the different dimensions. In 1994, scientists discovered dualities, which produce the same effects in four-dimensional space-time from various configurations. They also found p-branes, which take up two or more dimensions in space, while particles are 0-brane and strings are 1-brane. Supergravity, string, and p-brane theories could all be estimations of one overarching theory, and useful in their own ways.

Hawking briefly outlines more modern theories that consider the universe from new perspectives, which do feature some agreement and consistency with string theory. It seems each of these theories is merely a reflection of the unifying theory that would comprehensively explain all of the gaps between all of the partial theories.

Hawking suggests there might not be one single formula to the unifying theory, just as Gödel showed there was no one formula to arithmetic. Instead, it might be better to see science as a patchwork of maps that overlap and together provide a whole view. All the maps would agree on points they overlap on.

Yet, perhaps there is no one, single theory of everything after all. Perhaps humans will have to rely on overlapping theories that will continue to provide more accurate predictions. The process of scientific discovery could therefore continue indefinitely.

There are three possibilities: there is a unifying theory of physics; there are only partial theories, but they add up to explain everything; or the laws of the universe are random. Some argue the third in order to leave room for God. With our understanding of the uncertainty principle, we have removed the third option. Activity is random to a certain degree, but laws do hold sway in the universe.

Hawking discounts the third option on the basis it does not agree with observation—scientific laws have done a good job so far in predicting outcomes and explaining the universe. He suggests that any argument against that fact is based on prejudice, and the primary example he gives is the stubbornness people turn to in protecting their religious beliefs.

The second possibility agrees with what we have seen so far. Scientists have always found new phenomena to explore, and they may well find a new layer of particles beyond quarks. But gravity might limit this otherwise infinite series of discoveries as we achieve higher energy production rates. There are upper limits of energy after which black holes form just from one particle. Though scientists cannot achieve these levels of energy anytime soon, these high energies were around at the beginning of the universe, so studying that era could uncover a unifying theory within this lifetime.

The history of science so far has been the gradual accumulation of knowledge, and the replacement of older theories with ever-increasingly accurate explanations. Every new discovery has led to further questions, driving forward this race toward total knowledge. Hawking is optimistic that everything will one day be understood, even in the not too distant future.

Even if the unifying theory was found, it would still only be a theory, and could later be disproven. But if its predictions were consistent with observations, scientists could be confident in it. This would be the end of an era, one in which humanity strived for ultimate knowledge of the universe. It would also revolutionize the ordinary person's view of the universe. Today, scientists specialize in certain fields, and no one can stay up to date on all subjects. Eddington suggested only two people understood the theory of general relativity in his day. Today many thousands do. If we were to find the unifying theory of physics, in time everyone could understand it.

Throughout the ages, humans have always looked up at the sky and wondered about the universe, and how it all works. Today, even scientists cannot keep up with the rapid flow of new discoveries in every subject. But after finding one unifying theory of the universe, after all the currently unsolved mysteries are answered, there would be time for everyone to gain a general understanding of it. After all, these are questions that all humans share.

But even with such a theory, scientists cannot predict exactly the events of the universe, due to the uncertainty principle and the fact the math is simply too hard. While scientists know in essence how most of the universe works, that does not help to mathematically predict human behavior, for example. It will take longer to create useful approximation methods, even after the theory is found. So, the first step is finding the theory. The next step is *understanding* everything, including the reason for humanity's existence.

Humans looked at the sky not only to wonder at the mysteries of the universe, but also with uncertainty of their own role within that wider realm of existence. Finding a unifying theory would only be the first step in answering this more complex question, as the theory can provide the tools to predict *the universe. The next step will be applying that knowledge to truly understand it, helping humans to see where they fit in.*

CHAPTER 12

The world is confusing and people everywhere seek to understand it, as well as humans' place in it all. To do so, we create a world picture, whether it is an infinite tower of tortoises with the flat earth on their back, or string theory. Although the latter is more precise mathematically, it lacks observational evidence just as much as the former. Yet, the tortoise theory predicts people could fall off the edge of the world, and we know they don't.

Hawking argues that everyone has a theory of the universe, their own worldview, that has inherent predictions about the world and its constituent parts. Scientists' role is to observe the universe and its phenomena in order to provide accurate and logical world views that offer useful predictions.

The first attempts to explain the world involved unpredictable, humanlike spirits. But later, regularities were noticed, like the sun always rising in the east. Thus it was thought, there might still be gods, but they obeyed strict laws. Over the last 300 years in particular, these laws have been ever more minutely explored.

Since the dawn of the earliest human civilizations, people have created theories of the forces that govern the world's laws. Over time, these became more rational and scientific, based on direct observation of the universe's regular cause and effect. The pace of this progress has been exponential.

The successes in that period led some, like Laplace, to think scientists could predict everything, even human behavior, if only they knew the complete make up of the universe at one given point. But his idea did not say how the laws that govern such activity were set, or how the universe looked at the beginning. These aspects were in God's hands, who was largely left to the areas that were not yet understood.

While science gained increasing popularity as an approach to understanding the world, those areas that remained unknown and unknowable (at the time at least) remained within the realm of religious thought. God was useful, like the anthropic principle, for answering certain tricky questions.

Today, Laplace's approach is defunct because of the uncertainty principle of quantum mechanics, which introduces a minimum level of randomness. Quantum theory gives particles less well-defined positions and velocities to deal with this inherent inability to accurately measure them. But the calculations are more accurate when considering the particles as waves. Perhaps there are no positions and velocities, and there are only waves. The unpredictability comes from a mismatch of preconceived ideas and actual reality.

Over time, science came to incorporate more complex theories, such as the innate randomness in all of the universe's activities. This necessitated rethinks of many major phenomena and laws. Hawking suggests that despite the lengths science has come, perhaps scientists are still too hesitant to let go of the more entrenched ideas, such as particles. The key to progress is objectivity.

The purpose of science is now to identify the laws that allow us to predict events. But, the question comes back round to how these laws were chosen. Gravity has taken prominence in this book because it forms the large-scale structure of the universe, despite being the weakest of the four main forces. Gravity was incompatible with the previous misconceptions the universe was unchanging.

Modern science is now focused on predicting *the universe, within the limits of its randomness. To do so, scientists must look back, to understand how the universe came to be in its current state. Unraveling the mysteries of the early universe could provide crucial clues.*

General relativity states there must have been a point of infinite density at the beginning, the big bang. The universe would return to such a point in a big crunch. The theory also predicts other, localized singularities in black holes. The laws of science break down at these singularities, allowing room for God to work.

General relativity is an incomplete theory because it predicts its own breakdown at key moment in the lifecycle of the universe, as described by its own laws. As such, there is plenty of room left for God, as Hawking as shown throughout; religion seems to survive best in the areas remaining unknown.

Introducing quantum mechanics, however, leads to ideas of a finite, four-dimensional space with no boundaries. This could explain much of what we observe, including the wider uniformity of the universe and its irregularities, like stars or people. But if there are no boundaries, there is little room for God. Einstein asked what choice God had when making the universe. If the no boundary model is accurate, the answer is he had no freedom at all over initial conditions, although he could have still created the laws of science.

Hawking quotes Einstein's question to demonstrate how God has remained within the scientific debate even as his role has diminished. While the big bang fits well with religious teachings, the no boundary concept pushes God even further out of the model. Yet Hawking notes there could still be a creator that determined the rules that govern that universe.

Even if scientists find the unifying theory of physics, it is still just a set of laws. What is it that breathes life into the universe? Would such a theory require a creator? Many scientists are too preoccupied with questions of *what*, rather than *why*. Philosophers tend to ask these questions, but struggle to keep up with the fast pace and technical nature of modern scientific discovery.

Even with a unifying theory, questions would remain, such as where that theory itself came from, and why it has the power it does. These are questions philosophers, and by extension religious teachers, consider. By noting this, Hawking argues for a broader discussion on scientific topics, which requires better dissemination of scientific principles and understanding among a wider range of thinkers.

If a complete theory is found, over time it is likely to be distilled in a way that everyone can understand and engage with. Then everyone can discuss the big questions of why we and the universe exist. If humans can find the answer to that, it would be the same as knowing the mind of God.

Finding the unified theory of the universe is only the first step. The next is truly understanding the universe: the what, how, and why. *Once all of humanity's questions are finally answered, the human race would transcend its current era.*

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